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33 WEST 39TH ST· NEW YORK CITY

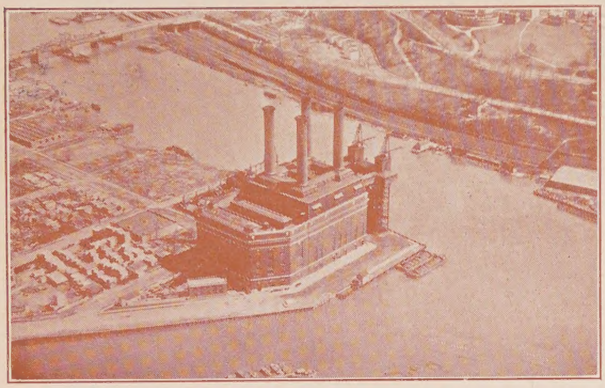
MIDWINTER CONVENTION NUMBER

A. I. E. E. Midwinter Convention

NEW YORK, N. Y., FEBRUARY 9-12, 1925

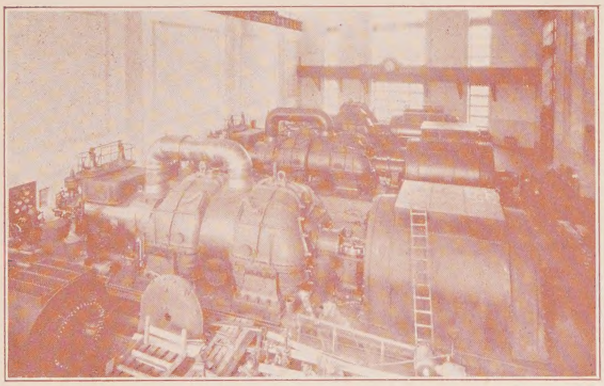
Some of the Prominent Engineering Plants to be Visited

(See Page 186 for a Complete List of Inspection Trips.)

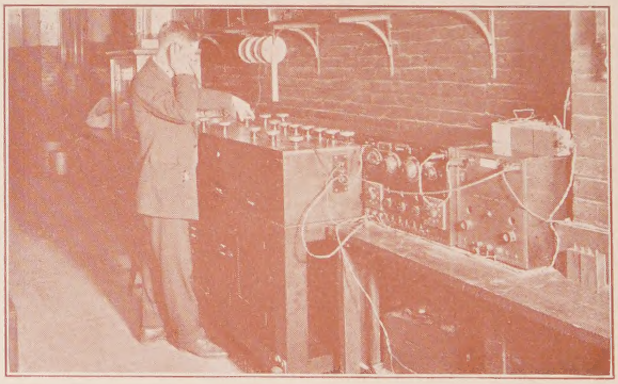


SHERMAN CREEK STATION OF THE UNITED ELECTRIC LIGHT AND POWER CO.

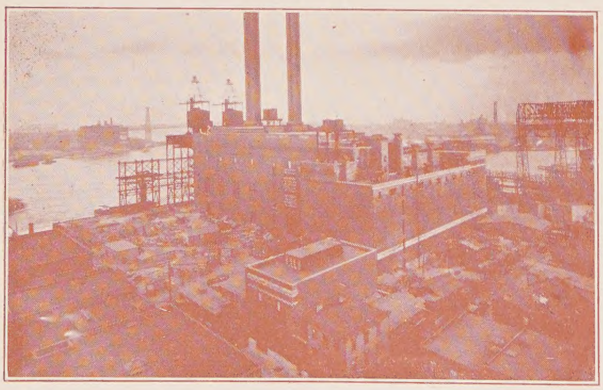
HISTORICAL MUSEUM—BELL TELEPHONE LABORATORIES INC.



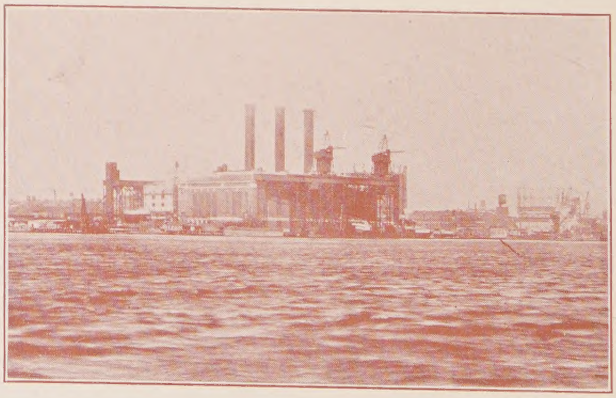
62,500-KV-A. TURBO-GENERATORS—HUDSON AVE. STATION BROOKLYN EDISON CO.



CARRIER CURRENT TESTING LABORATORY BELL TELEPHONE LABORATORIES, INC.



HUDSON AVE. STATION OF THE BROOKLYN EDISON CO.



HELL GATE STATION OF THE UNITED ELECTRIC LIGHT AND POWER CO.

JOURNAL

OF THE

American Institute of Electrical Engineers

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Institute and Related Activities

A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any change in business connections.

American Institute of Electrical Engineers

COMING MEETINGS

Midwinter Convention, New York, February 9-12
Spring Convention, St. Louis, April 13-17
Annual Convention, Saratoga Springs, June 22-26
Pacific Coast Convention
Regional Convention, Cleveland, May 22-23
Regional Convention, District No. 1, Swampscott, Mass., May

MEETINGS OF OTHER SOCIETIES

American Institute of Mining Engineers, New York, N. Y., Feb. 16-19
New Mexico Electrical Association, Albuquerque, N. M., Feb. 16-18
The American Physical Society, Joint Meeting with The Optical Society of America, New York, N. Y., Feb. 27-28
The American Physical Society, Pasadena, March 7
Illinois State Electric Association, Hotel Sherman, Chicago, March 18-19
Southwestern Div. N. E. L. A., Eastman Hotel, Hot Springs, Ark., April 21-24: Middle West Div., Omaha, May 20-22
American Electrochemical Society, Niagara Falls, N. Y., April 23-25
National Electric Light Association, San Francisco, June 15-19

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLIV FEBRUARY, 1925 Number 2

Some Thoughts on Research

Many engineers, electrical and others, as well as many industries, are giving attention to research work along the lines of pure science as well as applied science in the realization of the importance of the results from properly directed effort in such study.

No one can foresee what may be the result of searching for truth in the fundamentals of science upon which are based practical applications. Research committees of the several national societies have, for a good many years, carried on in their respective lines with excellent results and a further interest was given to this work in the gift by the friend of engineering, Mr. Ambrose Swasey in the establishment of "Engineering Foundation" for the purpose of providing the means whereby this most necessary phase of Science and Engineering might be promulgated.

The time seems to be at hand for all of us to give attention, in view of the inestimable value of the results of proper research, to the coordination of efforts now being made, and the husbanding of the energies now being expended towards the economic end of obtaining the most that is possible from the rather limited number of experts in this field of endeavor, as well as the relatively restricted funds now nationally available for the purpose.

Engineering Foundation, with its plan of trust, may very safely be the custodian of any funds placed to the capital account of a national principal sum, and the interest of such shall be guided into the most immediately necessary and useful channels of investigation.

Let all engineers give constructive thought to the whole research situation; from the development of the under-graduate for such work to the development of his teachers, and the making of a place in industry for practical and remunerative work, in order that this very important part of our technical life may go forward, hand in hand, with the apparently more active part so frequently and consistently brought to our attention through new practical applications based on the fundamentals of our science.—Farley Osgood.

New Branch Established at New York University

A new Branch of the Institute has been organized at New York University, New York City, and the first meeting held on December 5 indicated that this will be an active addition to the list of Branches.

The appointment of officers and committees and an address formed the program for the meeting. Donald Wright was elected Chairman and J. P. Della Corte local Secretary. Messrs. Jaboolian and Wright were appointed to act with the Chairman on the program committee, and Messrs. Natvig and Reimold were appointed as the membership committee. The organization of this Branch has been accomplished through the initiative and activity of Prof. J. Loring Arnold.

At this first meeting there were 87 in attendance. The seventeen seniors in the electrical engineering course are members of the Branch and many of the members of other classes will also be enrolled.

The speaker at the meeting was J. C. Clendenin, head of the automotive-engineering department of the General Electric Company plant at West Lynn, Mass. He presented the unit system of organization as employed by his company explaining the benefits of a coordinated system. He also mentioned the part that college-trained men play in this organization.

Freight Yard Floodlighting

To prevent damage to both rolling stock and contents of freight cars the Norfolk & Western railroad has installed electric floodlighting equipment in the freight yards of 15 main terminal points of its system.

These lights are mounted upon steel towers 70 feet high and at night provide the yards with an illumination that approaches daylight visibility.

In all, the railroad has put in place about 350 of these floodlighting units.

It has been found that in the terminal yards so equipped car numbers can be easily read at night in any part of the yard from a considerable distance.

Also, rails stand out clearly because of the reflection of the light upon their polished surfaces.

By using floodlighting units instead of older types of incandescent or arc lights placed much nearer the ground, blinding glare has been eliminated.

Switching crews are thus able to judge both speed and distance very much more accurately, and there has been a noticeable decrease in damage to both equipment and freight as well as a material shortening of time needed for making up freight trains.

Hand signal lanterns and other signal lights are not obscured by flood-lighting as with arc lights. In addition to all this the amount of freight lost by pilferage in yards equipped with electric flood lighting has decreased, because the general illumination of these yards approaches that of daylight in visibility and does not afford protecting shadows for thieves.

Some Leaders of the A. I. E. E.

Francis B. Crocker, the eleventh president of the A. I. E. E., was born in New York, on July 4, 1861. He was graduated from the School of Mines, Columbia University, in the year 1882, and shortly thereafter with Charles G. Curtis, formed the firm of Curtis and Crocker, patent attorneys and patent experts.

During this period Mr. Crocker spent much time in electrical research and took out a number of important patents.

In the year 1886 the two partners established the C. and C. Electric Motor Company, Mr. Crocker remaining until 1888, when he resigned to join Dr. S. S. Wheeler in forming the Crocker-Wheeler Company.

When the department of electricity was established at Columbia University in the year 1889, Mr. Crocker was placed in charge, being advanced to a full professorship in 1893. He remained in this position throughout a period of twenty years, resigning in 1913 on account of poor health.

Professor Crocker was one of the outstanding pioneers of the electrical industry. His work particularly in connection with the design and development of standard electric motors was a distinct and timely contribution to engineering advance.

He was chairman of the A. I. E. E. committee which formulated the first Standardization Rules, and of later committees which revised these rules. He was chairman of the conference of engineering and insurance representatives which drew up the provisions of the first National Electric Code. He was president of the A. I. E. E. during the term 1897-1898. He was secretary of the International Electric Congress and president of the Electric Power Club. In his time he wrote several books on electric subjects, and numerous technical papers. He died on July 9, 1921.

Operation of D-C. Motors on A-C. Circuits

Any d-c. series motor will run on alternating current provided sufficient voltage is applied to the terminals, but satisfactory operation on alternating current depends upon a great many factors.

When operating on direct current a certain portion of the line voltage is absorbed by the resistance drop in both the field and armature, the balance of the voltage being that which determines the speed of the armature at any given load. When operating on alternating current a certain portion of the line voltage is also absorbed by the resistance drop in the field and armature windings, but in addition to this there is an inductive drop which absorbs still more of the applied voltage leaving less available for producing torque and speed. Consequently the motor has a marked tendency to run at lower speed on alternating current than on direct current.

This inductive drop increases with the frequency of the alternating-current supply and consequently less useful voltage is available on high frequencies than on low. The design of the motor also has a very considerable bearing on the inductive drop and certain features can be incorporated to reduce it to a minimum. The inductive drop in the armature can be substantially eliminated by a compensating field winding at right angles to the main field having approximately the same number of ampere turns as the armature winding. This naturally requires a special construction that would not be found in the ordinary d-c. series motor. The inductive drop in the field cannot be compensated but may be reduced by a weak field design using the minimum number of field turns, although there are limits to this procedure as the commutation becomes less satisfactory as the field is weakened.

From this it is also obvious that high-speed direct-current motors will operate more satisfactorily on direct current than those wound for the lower speeds.

For alternating current operation it is necessary to have the entire magnetic circuit well laminated on account of eddy current losses.

The reason that some motors designed for direct current will not even start on alternating current is that the inductive drop combined with the resistance drop is so great that insufficient active voltage is available to produce enough torque to overcome the friction.

Series motors designed for use on both alternating-current and direct-current circuits at the same voltage are manufactured commercially in sizes of one h. p. and below. The smaller ones are constructed without compensating winding and most ratings above ¼ h. p. employ such windings. Motors of these types are known as "Universal" motors. At rated torque, the speed on any frequency up to 60 cycles will in general be within 10 per cent or 15 per cent of the speed on direct current at the same voltage. In order to attain this result the full-load speed cannot be much less than 4000 to 5000 rev. per min., depending upon the size of the motor.

Various other features such as the number of commutator bars, thickness of brushes, etc., enter into the design of a satisfactory universal motor to a different degree than would be the case if the motor were to be operated on direct current only.

Landing Lights for Mail Planes

"Night Lights" for pilots flying United States Air Mail Planes have been installed recently on all planes in the western division of that branch of our mail service.

The new lights are placed on the ends of the lower wing and are of about 450,000 beam candle power each.

From an altitude of five hundred feet these lights illuminate landing space for a distance of over half a mile, and are an invaluable aid to pilots who must make landings at night.

Effect of Full Voltage Starting on the Windings of Squirrel-Cage Induction Motors

BY J. L. RYLANDER[1]
Member, A. I. E. E.

Synopsis.—This paper discusses the effect on the windings when starting squirrel-cage induction motors with full voltage. The data is presented in four groups: namely, (1) Special tests made with a vibrograph instrument on a 50 h. p. and a 500 h. p. induction motor: (2) Observation tests made on a number of motors when starting with full voltage: (3) The condition of some windings which failed in service: (4) Formulas which show the main factors involved in the bracing of induction motors. Induction motor coil bracing in general is discussed.

* * * * *

It is well known that a heavy starting current is required when starting squirrel-cage induction motors with the customary auto-transformer starter. When starting these motors by connecting them directly to the line a starting current that is even heavier is drawn from the line, which, in itself, is undesirable. However, on certain applications it is desirable to have motors start from rest or at some reduced speed without the aid of an attendant when the power on the line fails and then comes again. This is accomplished by omitting the customary auto starter and connecting the motor directly to the line, thereby impressing on the winding full-line voltage instead of reduced voltages of 50, 65, or 80 per cent.

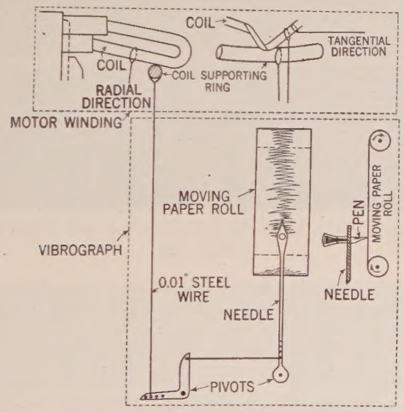

Fig. 1—Diagrammatic Sketch of Vibrograph Machine and Method of Connecting it to Windings

The effect of full voltage starting on the windings of squirrel-cage induction motors is discussed under four sub-headings; namely—

The special tests made on two motors.

The tabulated observations on a number of motors when starting with full voltage.

The condition of windings which failed in service.

And in formulae which show the main factors involved in the bracing of induction motor windings.

Two motors were chosen for making thorough tests; one was a 50-h. p., three-phase, six-pole, 440-volt, 60-cycles, 1160-rev. per. min., squirrel-cage motor, the other a 500-h. p., three-phase, four-pole, 2220-volt, 25-cycle, 724-rev. per. min. squirrel-cage motor. The windings were of the open-slot type. There was no special coil bracing on these motors.

The deflection of the coils was measured with the aid of a special measuring device called the "vibrograph". The vibrograph is an instrument which transfers motion to a place where it can be recorded as well as magnified. It consists essentially of a moving roll of paper on which a pivoted ink-pen records the movements of the pen, which is fastened, through an arrangement of levers, to the place of motion. The purpose of the levers is to magnify the motion. The vibrograph, therefore, shows the characteristics and magnitude of the deflections. A 0.01 in. diameter steel wire was fastened around the part of coil or supporting ring on which the vibration was to be measured, and this wire

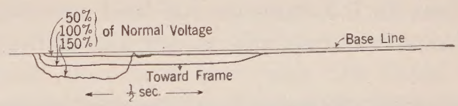

Fig. 2—Diagram of Coil Motion, 50-H. P., 440-Volt, Six-Pole, 1160-Rev. per Min. Induction Motor (Three Separate Vibrographs Grouped Together)

was connected to a leverage arm of the vibrograph machine. Measurements were taken at the middle and the end of the coils on the outside circumference and also on the coil supporting ring which is roped to each coil. In most of the readings taken the steel wire was in a radial position and in others the wire was in a tangential direction at right angles to the coil. Fig. 1 shows a diagramatic sketch of the vibrograph machine and the method of connecting it to the windings. Oscillograph curves of the current were also taken at the same time.

Fig. 2 is a tracing of three separate vibrograph diagrams grouped together for convenience. This shows the effect of starting the 50-h. p., 440-volt motor with 220, 440 and 660 volts, which corresponds to 50, 100 and 150 per cent of the normal voltage. The motor was connected directly to the line with a three-pole switch. The motor was without load. With 220

1. Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-12, 1925.

volts, the coils moved 0.002 inch, and several seconds were required to bring the motor to full speed. With 440 volts the coils moved 0.01 inch and required 1 second for the motor to reach full speed. With 660 volts the coils moved outward 0.016 inch for 0.4 second until the motor reached full speed. In all three cases the winding pulled away from the rotor and toward the frame. With 440 and 660 volts, the movements could

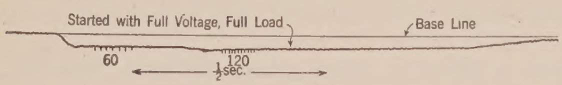

Fig. 3a—Coil Movement of 50-H. P., 60-Cycle, 440-Volt when Started with Full Voltage and Full Load

be observed with the eye and appeared to be larger than the measurements recorded by the instrument. The movement is for the radial direction.

Fig. 3a shows the coil movement of the 50-h. p., 440-volt, 60-cycle motor when started with full voltage and full load. The motor was connected directly to the line with a 3-pole knife switch. The winding moved outward toward the frame 0.01 inch, when the motor was started, and then vibrated while in this position for 1¼ seconds until the motor attained full speed. This curve indicates that the winding vibrated 60 times per second soon after the closing of the switch, but the vibrations soon changed to 120 per second. The motion is in the radial direction. Fig. 3b shows the oscillograph curve of the current which was taken simultaneously with Fig. 3a. The maximum current was 360 amperes, or 6.3 times the full load current.

Fig. 4a shows the coil movement of the 50-h. p.,

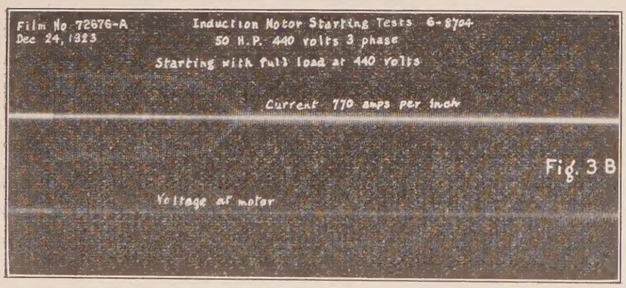

Fig. 3b

440-volt, 60-cycle motor when started with a standard auto-transformer starter. The starter was set at the 80 per cent voltage tap. The first part of the curve shows the coil movement when starting with 80 per cent voltage, and the second part of curve taken after a lapse of about two seconds shows the coil movement caused when changing from 80 per cent voltage to the full-line voltage by means of an auto-transformer starter which opens the circuit momentarily to make this change in voltage. The coil motion is for the radial direction. It will be noted that the winding moves quickly toward the frame as soon as the motor is started, and then gradually returns to the normal position and then toward the rotor; then when the change is made from the 80 per cent voltage to full voltage there is a quick movement toward the rotor followed quickly by another movement in the reverse direction of greater force than the preceding one. The winding then returned to the normal position. The cycle of movement to return to normal position required ½ second from the time the line voltage was applied. The writer has no explanation to offer for the first part of the curve for its peculiarity. This

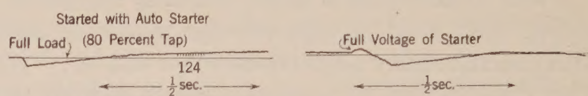

Fig. 4a—Coil Movement of 50-H. P., 440-Volt, 60-Cycle Motor When Started with Standard Auto-Transformer

peculiarity does not occur in the corresponding curve in Fig. 6b. The explanation for the movement of the winding in opposite directions as shown in the second part of Fig. 4a is that the normal direction of movement is toward the frame as in Figs. 3 and 5, and that when the circuit was momentarily opened, the residual

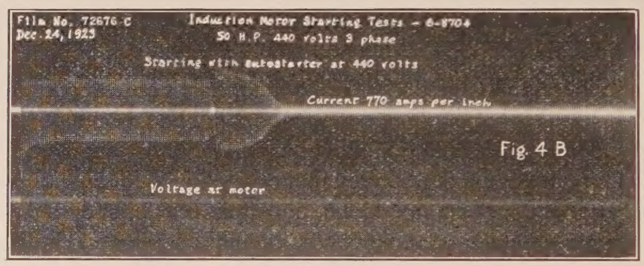

Fig. 4b

magnetization of the rotor induced a corresponding voltage in the primary, and this voltage was out of phase with the line-voltage which was then applied. Fig. 4b shows the oscillograph curve of the voltage and amperes taken simultaneously with Fig. 4a. The current at starting was 250 amperes, but the maximum current of 380 amperes flowed at the instant the line voltage was applied.

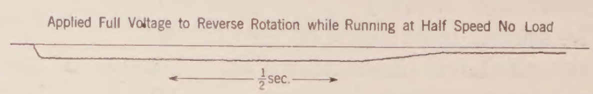

Fig. 5a—50-H. P., 440-Volt, 1160-Rev. per Min. Motor Started With No Load

In Fig. 5a the 50 h. p., 440-volt, 1160- rev. per min. motor was started with no load and the circuit was opened until the speed dropped to 600 rev. per min. Two of the primary leads were reversed while the motor was slowing down to 600 rev. per min. so that the motor would stop almost instantly and reverse its rotation. The switch was then closed. Fig. 5a shows that the windings moved 0.008 in. toward the

frame, and the total time required to stop the motor from half speed and bring it to full speed in the opposite direction was 1.3 seconds. Fig. 5B shows the oscillograph curve of the current which was taken simultaneously with Fig. 5A. The current taken was 380 amperes for the first second, which is 6.7 times the normal full load current.

Fig. 6 is a tracing of four separate vibrograph dia-

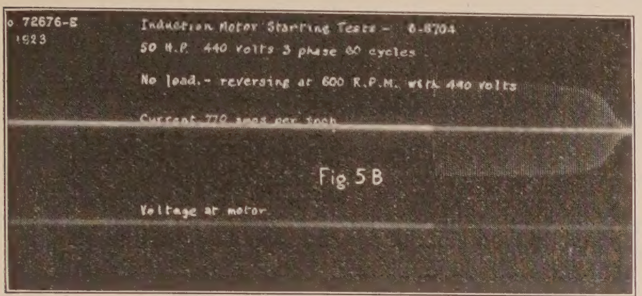

Fig. 5B

grams grouped together for convenience. These four curves are all for the 50 h. p., 440-volt motor, but in each case the motor was run on a 550-volt circuit. Curve *a* is for starting with 550 volts applied directly

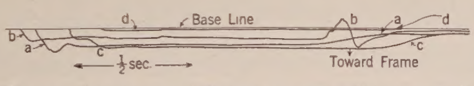

Fig. 6—Four Separate Vibrographs Grouped Together

to the winding. Curve *b* is for starting with an auto starter on the 80 per cent voltage tap. In Curve *c* the rotation was reversed while running at half speed with no current by reversing two of the leads and then

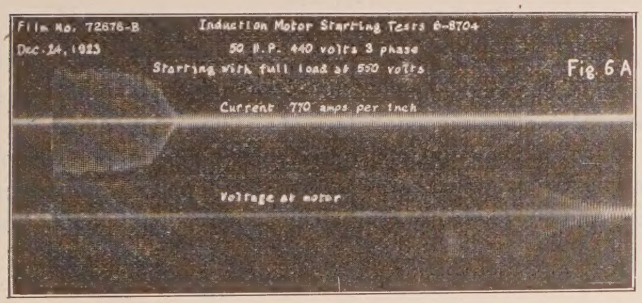

Fig. 6A

applying 550 volts. Curve *d* is the same as Curve *a* except that a coil-supporting ring was added to brace the winding. This ring was made from a ¼-inch diameter steel rod and each coil was tied to it with one turn of heavy twine. By adding the coil support the movement of the coil was reduced from 0.012 inch to 0.002 inch. The *b* curve shows the coil movement quickly reversed itself in a more marked manner than occurred in Fig. 4A. The movement was radial and toward the frame for all curves except the *b* curve, which had a momentary movement toward the rotor before changing from the 80 per cent auto-transformer tap to the line voltage. Figs. 6A, 6B and 6C show the oscillograph curves of the voltage and current for the vibrograph curves 6 *a*, 6 *b* and 6 *c* respectively. In Fig. 6C the light in the oscillograph failed momentarily and therefore, omits the middle part of the curves.

Fig. 7 shows the coil motion for the 500 h. p., 2200-volt induction motor when it was started without load at 1100 volts. Note that the winding did not shift to either side but vibrated an equal amount about its normal position. The vibration is in the radial direction. This may be compared with Fig. 8, which is the the same except that it is for full voltage (2200) starting. With 1100 volts, the coils vibrated 1/16 inch for 2.7 seconds until motor was up to speed, and with 2200

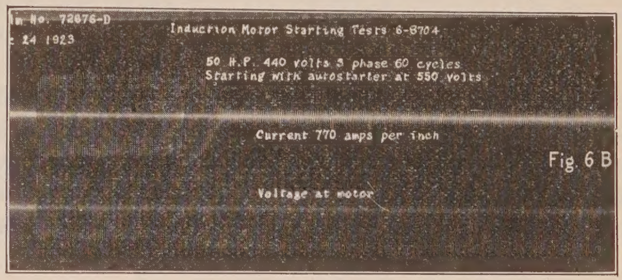

Fig. 6B

volts the coils vibrated ¼ inch (⅛ inch on each side of the normal position) for the 0.65 second required to bring motor to full speed. In Fig. 8 the coils vibrated 3/16 inch toward the rotor and 1/16 inch toward the frame and then held the position of 1/16 inch toward the frame after the motor was up to full speed. This curve gives the impression that the coils vibrated against something on the frame side 1/16 inch from normal, which prevented the winding from moving or vibrating beyond that point. This curve is for radial motion with the wire fastened at the middle of the end extension.

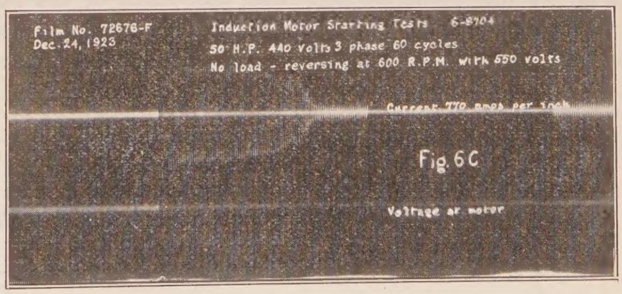

Fig. 6C

Fig. 9 is for tangential motion; otherwise it is the same as in Fig. 8. It shows that the tangential motion was almost ¼ inch (⅛ on each side of normal) and therefore about the same value as the radial motion. It also shows that the coils have a sidewise displacement of 1/16 inch to one side, which remains after the motor is up to full speed.

Fig. 10A was taken to show the effect of opening and closing the circuit similar to the action that occurs when using an auto-transformer starter. The motor was started with full voltage, then the switch was opened at the end of one second and closed again at the end of two seconds, and then opened at 2¼ seconds and closed after 3 seconds, then opened after 3⅓ seconds. The vibration was ¼ inch when the switch was closed

tained by exerting a force through a spring balance and measuring the deflections by the vibrograph.

Fig. 14 shows the radial force exerted on a coil of the 50 h. p. motor at the different voltages. It is plotted from data in Figs. 12 and 13.

General Discussion of Curves

These curves show that there was either quivering,

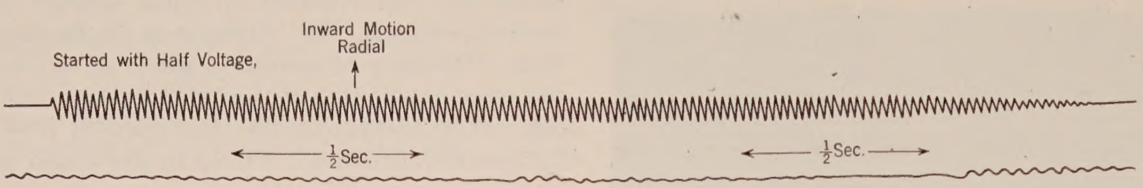

Fig. 7—Diagram of Coil Motion for 550-H. P., 2200-Volt Induction Motor When Started Without Load at 1100 Volts

the second and third time, the same as when started the first time with full voltage. Fig. 10B shows the oscillograph curve of the voltage and current which saw taken simultaneously with Fig. 10A. Fig. 10B, as well as curves in Figs. 3B and 6A, show that a voltage

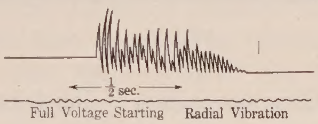

Fig. 8—Diagram of Coil Motion for 550-H. P., 2200-Volt Induction Motor When Started Without Load at 2200 Volts

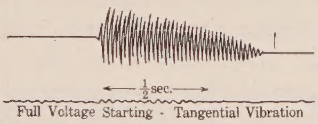

Fig. 9

is induced in the primary winding after opening the switch to the supply circuit.

Fig. 11 has been plotted from test data of the 50-h. p. motor, to show the effect of different voltages on the time in bringing the motor up to full speed. Like-

vibration or displacement of the windings when the motor was started in all of the tests on these two motors. The severity of the motion or displacement increased as a function of the square of the voltage applied to the particular winding; that is, a 440-volt or 2200-volt motor is no worse than a 220-volt motor with regard to

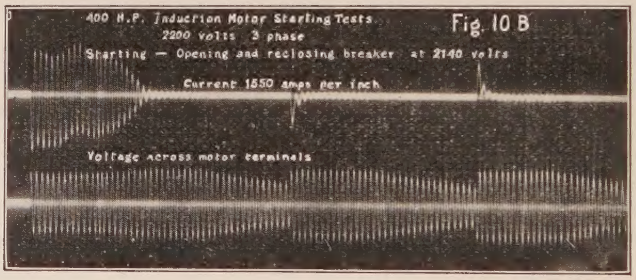

Fig. 10B

the effect of voltage alone, but 440 volts will produce four times as much coil displacement as 220 volts on a particular winding regardless of the voltage rating.

When the windings were displaced, the displacement was toward the frame in all cases except when starting the motor with an auto-transformer starter. The

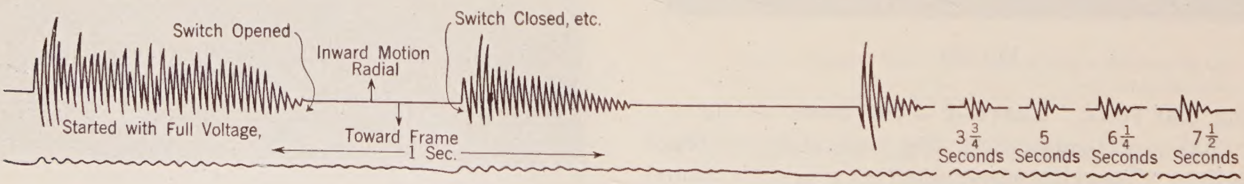

Fig. 10A—Effect of Opening and Closing Circuit Similar to Action which Occurs when Using Auto-Transformer Starter

wise, Fig. 12 shows the actual displacement of the ends of the coils as a function of the voltage.

Fig. 13 shows that the radial displacements of a stator coil are directly proportional to the force applied to the coil within the limits measured. This was ob-

windings move and vibrate in both radial and tangential directions.

The amount of coil movement and its duration, as shown in the vibrograph curves, correspond with the starting current on the oscillograph curves taken simul-

taneously with them. The length of time that the windings are displaced by the starting current for any two voltages on a given winding is inversely proportional to the square of the ratio of these voltages. The radial displacement of the stator-coil ends for any two voltages applied to these windings was proportional to the square of the ratio of the voltages within the limits measured. Therefore, the length of time in seconds that the windings vibrate, multiplied by the coil displacement in inches, will give a constant value regardless of the voltage applied. The addition of a coil supporting ring, as in Fig. 6D, shows that additional coil bracing reduces the coil movement considerably.

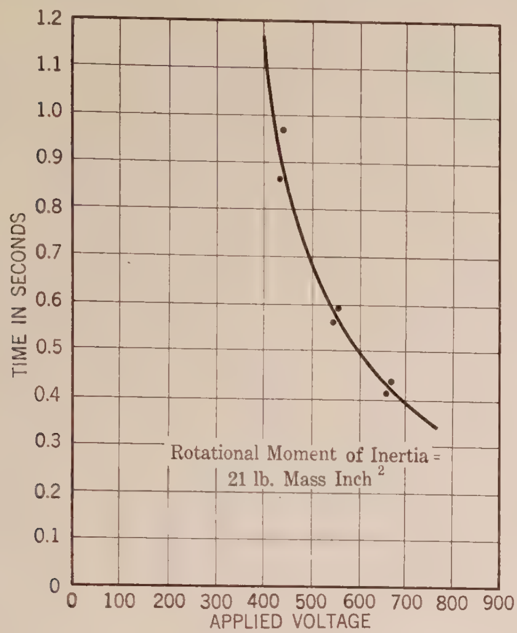

FIG. 11—EFFECT OF DIFFERENT VOLTAGES ON TIME IN BRINGING MOTOR TO FULL SPEED

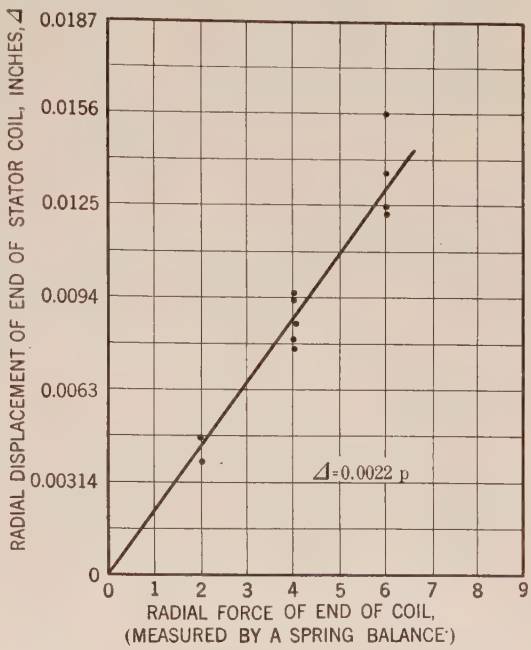

FIG. 13—RADIAL DISPLACEMENT OF STATOR COIL

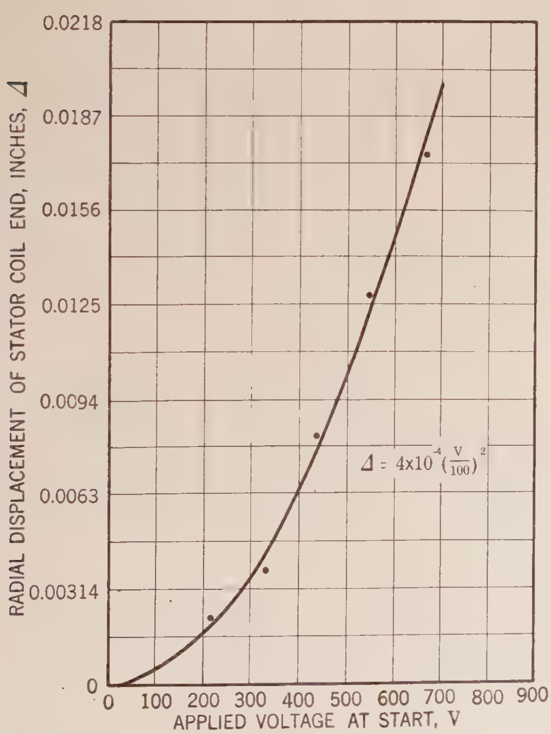

FIG. 12—ACTUAL DISPLACEMENT OF ENDS OF COILS AS A FUNCTION OF VOLTAGE

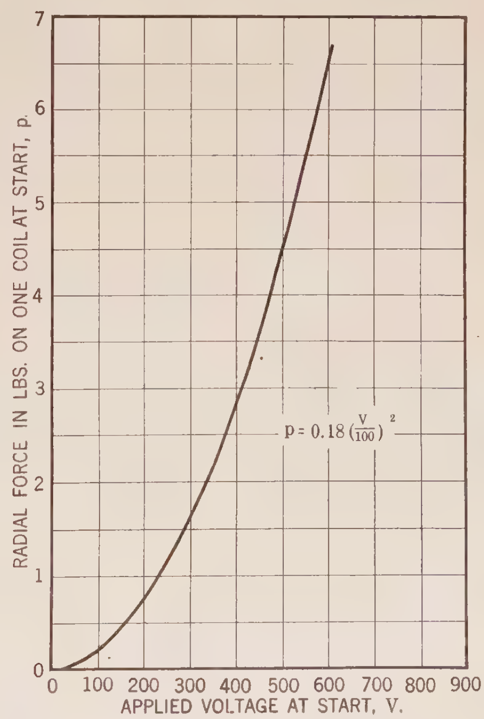

FIG. 14—RADIAL FORCE EXERTED ON COIL OF MOTOR FOR DIFFERENT VOLTAGES

Figs. 3B, 6A and 10B show that there is a voltage at the motor terminals after disconnecting the supply circuit from squirrel-cage induction motors. For the 50 h. p. motor with full load, the induced voltage is

25 per cent of normal voltage, half a second after open- the switch, and on the 500 h. p. motor with no load, the induced voltage is 50 per cent of full voltage 3/4 second after opening the switch and 35 per cent after 1 3/4 seconds. In the primary this voltage is induced by the residual magnetism of the rotor, and the frequency is directly proportional to the speed of the rotor which is slowing down.

Starting motors with full voltage produces a severe strain for a short period, whereas the use of an auto-transformer starter produces a less severe strain for a longer period and also a momentary strain that may be more severe than when starting with full voltage. The auto-starter may produce two severe shocks on the winding in opposite directions. This is accounted for by the voltage which is produced in the winding being out of phase with the line voltage at the instant of changing from the lower-voltage tap to the full voltage tap of the auto-starter.

What Observation of Windings has Shown

In addition to the two motors on which oscillograph and vibrograph curves were taken, other machines as listed below were started with the full-rated voltage on the terminals and the effect observed:

H. P.	Volts	Poles	Coil Extension	Starting Current	Effect on Winding
50	440	6	4 1/2	6 × Full Load	Moved slightly
400	2200	4	11	7.5 × Full Load	Considerable movement on coils and complete winding
250	220	24	5 3/8	4.4 × Full Load	Quivered slightly
400	2200	24	5 5/8	5.7 × Full Load	Quivered slightly
600	2200	2	9	9.8 × Full Load	Appreciable movement of complete winding
10	220	4	3 3/8	5.2 × Full Load	No effect: This winding is made solid by dipping the complete winding in varnish and baking it. No other bracing used.

When the effect on the windings is slight, nothing is seen with the eyes, but any quiver or vibration of the windings is felt with the hands without difficulty. Some of these windings not only vibrated but had a definite movement which lasted as long as the heavy starting current flowed through the windings. These movements of the windings were such as to separate the windings wherever the phases change and for the winding to move away from the rotor and toward the frame. When the vibration of the winding is severe, a distinct hum is heard.

Motors Failing Due to Distortion of Windings

Some machines which had been in service for years finally failed due to distortion of the windings. These machines had used the customary auto-starter method of starting. Whether the cause of the distortion was due to the starting current or to some other disturbance, such as short circuits on the line near the motor, was not known. These windings showed the following effects:

1. The windings had separated between phases.
2. The windings had moved away from the rotor and toward the stator.
3. The top and bottom layers of coils had drawn together.

The separation between phases and the movement toward the frame was also seen on some of the windings that were observed while they were being started. The action of top and bottom layers on each other cannot very well be observed, but from the formulas which follow, it should be expected that the top and bottom layers should draw together at certain places.

Derivation of Working Formulas

There is an attraction or repulsion between each and every other conductor and also between each conductor and the magnetic field of the secondary, and also with the stray leakage flux of the primary. On account of the complications involved, and because the action of conductors on each other is the main force involved, formulas have been worked up for this action only.

The force exerted between two parallel conductors is:

$$P = \frac{4.5 \times I^2 L}{a \times 10^8}$$

where P is the force in pounds, L is the length of the conductors in inches spaced a inches apart and having I amperes flowing in both wires. This force attracts when the current is in the same direction and repels when the current flows opposite directions.

The deflection of the conductors can be derived from the formula

$$D = \frac{P L^3}{48 E M}$$

where E is the modulas of elasticity $(11 \times 10^6$ for copper) and M is the moment of inertia =

$$\frac{b h^3}{12}$$

and where h is the dimension of the beam in the direction parallel to the applied force and b is the dimension at right angles to the applied force. D is the deflection in inches when b, h and L are expressed in inches, and the deflection

$$D = \frac{1.02 I^2 L^4}{a \times b h^3 \times 10^{15}}$$

By assuming a typical value of current density in the copper conductors of 2500 amperes per square inch and using a value of the starting current as being 6 times full load, the value 15,000 $b h$ can be substituted for I, and the deflection or amount of vibration becomes

$$D = \frac{2.3}{10^7} \times \frac{b}{h} \times \frac{L^4}{a}$$

where D is deflection in inches.

h is dimension of conductor in inches in the direction

parallel to direction of applied force, and b is the dimension of conductor in inches in direction at right angles to the direction of the applied force.

L is the length of conductors in inches between supports and a is the space between conductors in inches.

Coil Bracing

The attraction and repulsion of the conductors on each other tends to move the conductors and is opposed by the mechanical fastenings which support the conductors. Many of the conductors are secured by resting against other conductors, which are secured by various means. As all armature conductors pass through the slots, the slots become an effective means of securing a large part of each conductor. Beyond the slots a number of the conductors are bound together in a unit as a coil, and this prevents the conductors from vibrating against each other. Each coil end tends to move under the effect of the force exerted on it by all other coils in the machine but is resisted by the rigidity of the coil as each coil is held by being placed in two different slots and usually at one or more other places on ends of windings by means of rope, bolts, clamps or steel bands to other more or less fixed supports.

The formula for deflection shows that the dominating factor is the length between any two supports, as the deflection varies according to the fourth[2] power of of this length. This distance should, therefore, be kept within proper limits. As the deflection is also proportional to the square of the current, the coil movement will be four times as great for a motor which has a starting current ten times the full load value, as for the same winding with a starting current of five times the full load value. As two-pole and four-pole motors have relatively large coil extensions and also have the highest ratio of starting current to full load current, their windings must be braced much more firmly than others.

In many of the small motors the coils fit closely with each other and the complete winding is reinforced with varnish or impregnating compounds; therefore, their windings are exceptionally well braced to resist the forces exerted when starting the motors.

The vibration and movement of the windings deteriorate the insulation, and if sufficiently severe, will cause an insulation failure. It may also break the coil leads.

The kind and amount of insulation and the method of bracing are the limiting factors which determine how much vibration or coil movement can be permitted. The repetition of these vibrations sometimes has a cumulative effect by loosening the rope which is usually used to secure the coils to a supporting ring.

As the amount of vibration or coil movement is directly proportional to the square of the ratio of the starting current to the full-load current, the starting of squirrel-cage induction motors is much more severe on the windings than it is with wound-rotor induction motors where the current is limited by the resistance in series with the secondary. As the amount of vibration is also directly proportional to the third or fourth power of the length of coil between supports, very thorough bracing is required where the coil extensions are comparatively large. Nevertheless, there seems to be no question but that all induction motor windings can be satisfactorily braced to stand the mechanical effect of full voltage starting.

2. Although theoretical calculations show that the coil movement should vary according to the fourth power of the length between supports, some measurements have been made that indicate that it is more nearly the third power.

PRODUCTION OF SPONGE IRON

Experimental work in the production of sponge iron, conducted by the Department of the Interior at the Seattle, Wash., experiment station of the Bureau of Mines, has advanced to the point where it is believed that industrial applications of the process can be safely considered for the production of sponge iron as a metallurgical reagent for the precipitation of copper, lead, and numerous other metals from solution. In those regions remote from larger iron and steel making centers and where electric energy can be had at a comparatively cheap rate, sponge iron can also be converted into iron and steel products by melting in the electric furnace.

If a piece of iron oxide is completely reduced at such a low temperature that no sintering or fusion takes place, then the piece of metallic iron formed has the same size and shape as the original piece of oxide. On account of the removal of oxygen, the structure is finely porous, exposing a large surface of iron, and the apparent density is less than that of the original piece of iron oxide. The material is called "sponge iron."

When sponge iron is used as a metallurgical reagent in the precipitation of metals from a solution, the precipitation reaction takes place with greater speed than if the precipitating reagent is a massive form of iron, such as scrap or pig iron, and hence the use of sponge iron proportionately increases plant capacity. Sponge iron is likely to be of increasing importance in the hydrometallurgy of low-grade copper and complex ores. Its production insures a permanent and reliable source of metallic iron. It is probable that the future success of large-scale leaching and precipitating processes for copper and lead depends largely upon a supply of cheap sponge iron.

The process developed by the Bureau of Mines consists of passing a mixture of iron ore and coal through a rotating kiln heated at one end to a temperature sufficient to convert iron oxide to metallic iron, then discharging and cooling the product and passing it through a magnetic separator to remove the sponge iron from the residual coke and siliceous material.

Details of these investigations are given in Serial 2656, copies of which may be obtained from the Department of the Interior, Bureau of Mines, Washington, D. C.

The Theory of Probability
and Some Applications to Engineering Problems

BY E. C. MOLINA[1]
Member, A. I. E. E.

Synopsis.—The purpose of this paper is to encourage a wider recognition by engineers of a body of principles which in its mathematical form is a powerful instrument for the solution of practical problems. Some subjects in which the theory of probability has been used are recalled, the fundamental principles are stated and applied to three problems chosen from the field of telephone engineering

* * * * *

"THE subject to which I now invite attention has high claims to consideration on account of the subtle problems which it involves, its important practical applications and the eminence of those who have cultivated it." (Todhunter: History of the Mathematical Theory of Probability, 1865).

You are all familiar with the importance of the theory of probability in its applications to life assurance, biology, radioactivity and other branches of pure and applied science. In telephony the theory has been utilized for over a quarter of a century. This is not surprising. The calls to be handled during a busy hour fall at random with reference to a given instant. Hence, a knowledge of total and average loads does not suffice for determining the quantities of equipment required for rendering efficient and economical service. The mathematical theory of probability enables one to evaluate the frequencies of different deviations from known average conditions. With this information the solution of trunking problems becomes precise, the quantities of equipment required for existing systems is determined and as changes in the art occur the merits of proposed systems can be weighed, thereby assuring that the public's demands for service be met satisfactorily.

The theory of probability is of immediate aid in the planning of inspection programs which must be carried out in order that apparatus may leave the manufacturer in fit condition to perform its functions. The interpretation of empirical data is facilitated and often the application of the theory to hypothetical conditions makes unnecessary the carrying out of costly statistical investigations.

The application of the theory of probability to engineering problems is a subject of so much importance that it is believed the engineering societies could well afford to give more consideration to it than has been given in the past. While there have been one or two instances of Institute papers discussing probability matters, such, for instance, as "A Method of Determining Resultant Input from Individual Duty Cycles and of Determining Temperature Rating" by Mr. Bassett Jones, in general the Institute papers have paid little attention to this matter. It is the purpose of this paper to present the fundamentals of the theory of probability in a form which it is hoped will appeal particularly to practical engineers, and to discuss specifically the application of these fundamental principles to a number of practical problems.

The fundamental principles of our subject, first formulated in a comprehensive manner by Laplace in his classic "Théorie Analytique des Probabilités" may be stated as follows:

First Principle. The probability that an event may happen in a specified manner is the ratio of the number of ways it can happen as specified to the total number of ways in which it can happen. For example, the probability that an ordinary six-face die will, when cast up in the air, give a number greater than 4 is 2/6 since there are only two faces marked with numbers greater than 4; whereas, the total possible number of ways in which the die can turn up is obviously 6.

This first principle is really nothing more or less than a definition of probability. It is implicitly assumed that all the possible cases are equally likely or probable. This implicit assumption has been severely criticised by some philosophers. Moreover, Poincaré, Bertrand and others have claimed that a logically satisfactory definition is impossible. However, this statement should not be disturbing any more than being reminded that there is no precise answer to the question "what is matter?"—should disturb a group of chemists.

Second Principle or Theorem of Total Probability. When a complex event can be reduced to a group of *mutually exclusive* simple events, the probability for the complex event is the *sum* of the probabilities corresponding to each simple event. Or thus—the probability of the happening of any one of several events, no two of which can concur, is the *sum* of their separate probabilities. As an example, suppose that one of our men has plans to return from Chicago next summer either by the Pennsylvania R. R., the New York Central R. R. or else by boat through the Great Lakes. If p_1, p_2, p_3, are the probabilities for these three routes respectively, the probability that he returns by rail is

$$p = p_1 + p_2$$

1. American Telephone and Telegraph Company, New York, N. Y.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-12, 1925.

Third Principle. If there be given any number of *independent* events, the probability that they will all happen is the *product* of their respective probabilities. Suppose we have in front of us, three bags filled with red, while and blue balls. If 7 per cent of the balls in bag No. 1 are white, 19 per cent of those in bag No. 2 are white and 40 per cent of those in bag No. 3 are white and we draw one ball from each of the bags, then $P = (7/100)\ (19/100)\ (40/100)$ is the compound probability that all three of the drawn balls will be white.

Fourth Principle. The probability of the concurrence of two *dependent* events is the product of the probability of the first times the probability that when that has happened, the second will follow.

Fifth Principle. This fifth principle may be considered as a corollary to the fourth. Suppose we know the *a priori* probability in favor of an event which *has* happened and that we also know the *a priori* probability for a compound event consisting of the event which has occurred followed by another event which has not yet occurred. Then the probability that the second event *will* occur is equal to the *a priori* compound probability divided by the *a priori* probability of the event which has occurred. Example—Bids are open for the construction of a city subway. Let P be the compound probability that a certain construction company bids *and* submits satisfactory plans. Let p_1 be the probability that said company bids. Then, if the company *has* made a bid, the probability that the plans submitted will be satisfactory is $p_2 = P/p_1$.

We now come to a principle which is of fundamental importance for most if not all fields of engineering. The so-called "Theory of Sampling," which is of immediate interest to every engineer, seems to be inextricably tied up with this principle in spite of efforts made to separate them.

The five principles given above relate to the theory of *a priori* probability. The next principle has reference to *a posteriori* probability or probability of *causes.* The essential difference between *a priori* and *a posteriori* probability may be indicated as follows: Consider a bag containing 1000 balls some of which are white. We are dealing with the *a priori* probability when, *knowing the ratio of white to total balls* we put the question, what is the probability that 100 drawings will give 7 whites? It is assumed that a drawn ball is replaced in the bag before the next ball is drawn. We are dealing with *a posteriori* probability when, *knowing that* 100 *drawings did give* 7 *whites* we put the question, what is the probability that the ratio of white to total balls has a specified value, (say 11/1000 for instance)?

As before, we will follow closely in the footsteps of Laplace. His classic generalization of Bayes' theorem laid the corner stone for the edifice erected by mathematicians and statisticians since the publication of the *Theorie Analytique.* Two preliminary definitions will help us to understand Laplace.

Consider again the bag containing 1000 balls from which 100 drawings gave 7 whites. Note that the unknown ratio of white to total balls is a *hypothesis* or *cause* leading to the observed result. We may consider any one of 999 possible hypotheses:

1—ratio is	p_1	$= 1/1000$
2— " "	p_2	$= 2/1000$
3— " "	p_3	$= 3/1000$
K— " "	p_k	$= K/1000$
997— " "	p_{997}	$= 997/1000$
998— " "	p_{998}	$= 998/1000$
999— " "	p_{999}	$= 999/1000$

The *a posteriori* theory assumes that there is a known probability for the *Kth* hypothesis before the results of the drawings are disclosed. Call this the *existence probability for the Kth hypothesis.* If the *Kth hypothesis* exists there is a definite probability that it will give the observed result. Call this the *productive probability for the Kth hypothesis.*

Sixth Principle. The *a posteriori* probability in favor of a specified cause is a fraction whose numerator is the product of the existence and productive probabilities of that specific cause while the denominator is the sum of like products for all the causes.

Seventh Principle. If two events are governed by the same set of mutually exclusive causes and one event *has* happened, the probability that the second event *will* happen is equal to the sum of all the products obtained by multiplying the *a posteriori* probability of each cause (as determined from the observed event) by the probability that the cause, if acting, will produce the second event.

Applications. "The applications of the principles which we have just expounded to the various questions of probability requires methods whose investigation has given birth to several methods of analysis and especially to the theory of combinations and to the calculus of finite differences."[2]

As a telephone engineer the author need not apologize for being more familiar with the application of the theory of probability to telephone problems than to problems relating to other fields of engineering. In what follows, it is not intended to discuss at length any major telephone problem. Such a discussion would be worthy of at least as much space as has been allotted to this paper. Moreover, the inherent interest of a major problem would distract attention from the probability principles made use of in its solution.

As an immediate application of the first principle or definition of probability consider the following problem:

n calls fall at random in an interval of time A. As the calls fall they are automatically counted by a meter. This meter, however, cannot function properly if the time interval between two consecutive calls is less than a small interval a.

2. Laplace Théorie Analytique.

What is the probability that a correct count of the n calls will be obtained? In other words, what is the probability that no two consecutive calls will be separated by a distance less than a?

The mathematical analysis contained in the appendix to this paper gives

$$P = [1 - (n - 1)(a/A)]^n$$

The curves of Fig. 1 show the numerical values of the probability P for various values of n for the two

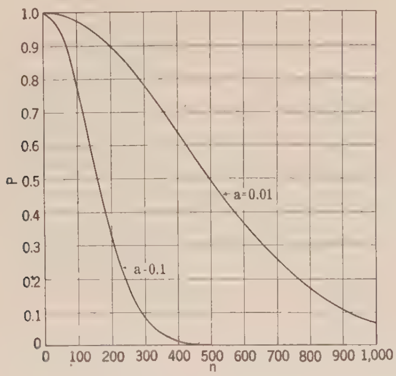

FIG. 1

cases $a = 0.1$ sec. and $a = 0.01$ sec. The large interval A is assumed to be one hour.

For an illustration of the applicability of the second and third principles consider the following telephone trunking problem.

Referring to Fig. 2 consider a group of 269 subscribers, each equipped with a 20-point line switch. The line switches have common access to a group of 20-trunk lines. When a subscriber removes his receiver

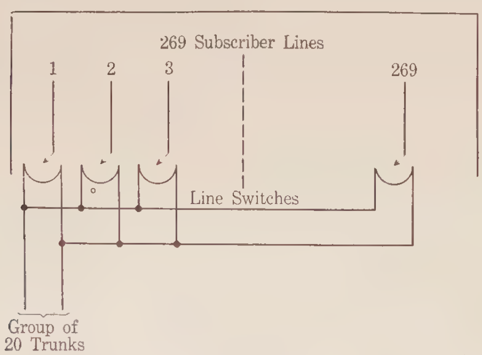

FIG. 2

from the hook, his line switch revolves and connects him to an idle trunk, if one exists.

What is the probability that when a particular subscriber, X, calls he fails to obtain a trunk at once?

It will first be shown that this trunking problem transforms into a simple dice-throwing problem. The answer to the dice problem is then obtained at once by recourse to the *binomial* expansion which was used so effectively by Mr. Bassett Jones in the solution of his problem. To facilitate the transformation, let us make some simplifying assumptions.

A—During the period of time under consideration, the busy hour of the day, each subscriber's line makes one call which is as likely to fall at any one instant as at any other instant during the period.

B—If a call, when initiated, obtains a trunk immediately, it retains possession of that trunk for exactly two minutes. In other words, a constant holding time of two minutes' duration will be assumed.

C—If a trunk is not obtained immediately, the calling subscriber waits for two minutes and then withdraws his call. If, while waiting, a trunk becomes idle, he takes it and converses for the interval of time remaining before his two minutes are up.

Referring to Fig. 3, let point P represent the unknown instant within the hour at which X calls. Consider the two minutes immediately preceding the instant P. Evidently, by assumption C, calls falling outside of this particular two-minute interval cannot prevent X from obtaining a trunk.

If, however, at least 20 of the remaining 268 subscribers initiate their calls within the particular two minutes under consideration, there will be no trunk line immediately available for X. This follows from assumptions B and C.

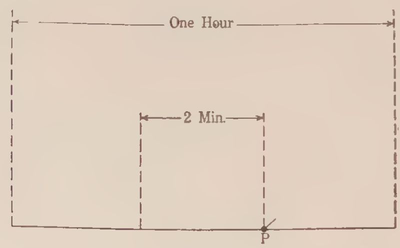

FIG. 3

Consider some one of these 268 other subscribers, for example Y. The probability that Y calls in the two minutes under consideration is, by assumption A, the ratio of 2 minutes to 60 minutes, or 1/30, which is exactly the same as the probability that he would throw an ace if he were to make a single throw with a 30-face die. Likewise, the probability that still another subscriber calls in the two minutes under consideration is exactly the same as the probability that this other subscriber should throw the ace in a single throw with a 30-face die.

It is evident then, that the probability that X fails to get a trunk immediately is the same as the probability of throwing at least 20 aces if 268 throws are made with a 30-face die. To facilitate the determination of this probability and the solution of similar problems, probability tables of the type shown in Table I have been computed. In the table, the average number of times an event may be expected is represented by a. The probability that the event occurs at least a greater number of times $c = a + d$ is represented by P. In the problem under consideration, the average

number of aces expected is $8.96 = \frac{268}{30}$. Likewise in the present problem $c = 20$. Turning to the table, we find that corresponding to $c = 20$ and $a = 8.96$, the value of the probability P is 0.001. In the particular telephone problem under consideration this means that once in a thousand times when X calls, at least 20 of the other subscribers will have called in the two minutes immediately preceding, and therefore X fails to get a trunk immediately. In other words, we may consider that on the average, one in every thousand calls is delayed.

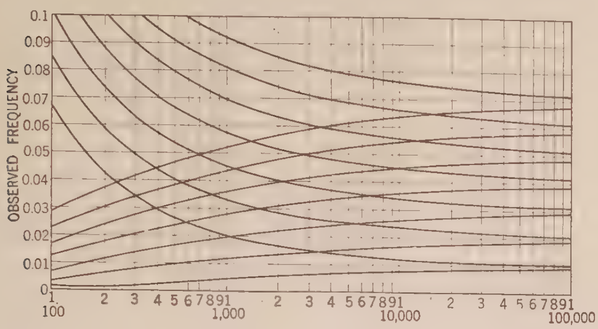

Fig. 4—Curves Showing Probable Range of True Frequency Vs. Number of Observations for Observed Frequencies of 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0 07. Weight = 0.98

Finally, as an application of that most far-reaching but much debated sixth principle, consider this telephone traffic problem:

A group of 50,000 calls originated in an exchange area. An unknown number of them were delayed more than 10 seconds. Observations were made on 300 of the calls and of these 9, or 3 per cent, were delayed more than 10 seconds. With this information is it a safe bet that the unknown percentage for the entire 50,000 calls is below 5? Or better yet, are we justified in betting 99 in 100 that the unknown percentage for the 50,000 calls is below 5? Or again, may we bet 8 in 10 that the unknown percentage is between 0.5 and 5? It is taken for granted that the observer is justified in believing that the calls under consideration fulfill the conditions of random sampling such as that each call is independent of every other call, or that an appreciable number of the calls is not due to the occurrence of some unusual event,—the Wall Street explosion, for example.

Obviously the telephone problem is analogous to the problem of the bag containing an unknown ratio of white balls. The corresponding elements in the two problems may be tabulated as follows:

1st. 1000 balls in bag vs. 50,000 calls originated.

2nd. 100 balls drawn vs. 300 calls observed.

3rd. 7 white balls drawn vs. 9 calls delayed more than 10 seconds (*i. e.*, defective with reference to a particular characteristic).

4th. To the 999 possible, hypotheses with reference to the unknown per cent of white balls correspond 49,999 possible hypotheses with reference to the unknown per cent of calls delayed more than 10 seconds.

The problems differ in that a ball drawn from the bag is returned before another drawing is made, whereas an observed call is comparable to a ball being drawn and not returned. However, with the numbers involved this discrepancy may be ignored.

The attached curves, Fig. 4 show graphically the conclusions to be drawn from the mathematical analysis. A glance at the right-hand end of the curves will show that they are associated in pairs. The upper curve of a pair slopes downward from left to right while its mate slopes upward.

Consider the pair of curves marked 0.03. For the abscissa 300, they give as ordinates the values 0.0625 and 0.014. The interpretation of these figures is as follows: if 300 observations gave 3 per cent of calls delayed then we may bet

1st. 99 in 100 that the unknown percentage of calls delayed is not greater than 6.25.

2nd. 99 in 100 that it is not less than 1.4 per cent.

3rd. 98 in 100 that it lies between 1.4 per cent. and 6.25 per cent.

Likewise, considering the curves marked 0.06 if 1000 observations gave 6 per cent of calls delayed, then we may bet

1st. 99 in 100 that the unknown percentage of calls delayed is not greater than 8.05.

2nd. 99 in 100 that it is not less than 4.4 per cent.

3rd. 98 in 100 that it lies between 4.4 per cent and 8.05 per cent.

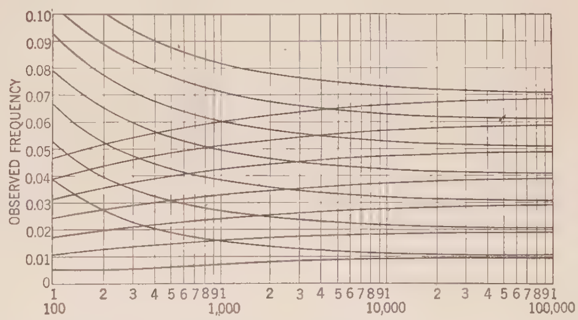

Fig. 5—Curves Showing Probable Range of True Frequency Vs. Number of Observations for Observed Frequencies of 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07. Weight = 0.08

It is obvious from the shape of the curves that a few hundred observations do not give more than a vague idea as to the unknown per cent of calls delayed. On the other hand, the gain in accuracy obtained by making more than 10,000 observations would hardly justify the expense involved. The number of observations which safety requires in any particular problem must be determined by the conditions of the problem itself. If we are willing to take a chance of 9 in 10 or 8 in 10 instead of 99 in 100 or 98 in 100, respectively, the curves of Fig. 5 will give us an idea of the range

within which the unknown percentage of defectives lies.

Appendix

Counting Meter Problem

n calls fall at random in an interval of time A. As the calls fall, they are automatically counted by a meter. This meter, however, cannot function properly if the time interval between any two consecutive calls is less than a small interval a.

What is the probability that a correct count of the n calls will be made?

Consider the two diagrams of Fig. 6. The lower diagram indicates any one of the many different number of ways in which the calls may fall. Evidently this number is the same as the number of different sets of values which we can give to the set of variables $y_1, y_2, y_3 \dots y_n$, so that each variable is equal or greater than zero, but their sum not greater than A. Using the language of the integral calculus, the number of possible sets of values for $y_1, y_2 \dots y_n$ is

$$\int_0 \int_0 \int_0 \dots \int_0 d\,y_1\,d\,y_2\,d\,y_3 \dots d\,y_n$$

where the upper limits of the integrals must be such as to satisfy the condition

$$O < \Sigma\, y < A$$

On the other hand, the upper diagram indicates any

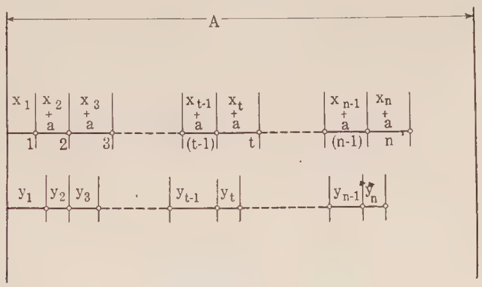

Fig. 6

distribution of the calls consistent with the condition that the distance between consecutive calls is not less than a. Note, that since there are n calls, there are $(n-1)$ intervals, each of which must not be less than a.

The number of distributions satisfying the desired condition is evidently the same as the number of sets of values which can be given to the set of variables $x_1, x_2, \dots x_n$ so that each variable is equal or greater than zero, but their sum is not greater than $A - (n-1)\,a$. The number of possible sets is given by the multiple integral

$$\int_0 \int_0 \int_0 \dots \int_0 d\,x_1\,d\,x_2\,d\,x_3 \dots d\,x_n$$

where the upper limits of the integrals must be such as to satisfy the condition

$$O < \Sigma\, X < [A - (n-1)\,a]$$

Therefore, the desired probability is

$$P = \frac{\text{(favorable cases)}}{\text{(total possible cases)}}$$

$$= \frac{\int_0 \int_0 \int_0 \dots \int_0 d\,x_1\,d\,x_2\,d\,x_3 \dots d\,x_n}{\int_0 \int_0 \int_0 \dots \int_0 d\,y_1\,d\,y_2\,d\,y_3 \dots d\,y_n}$$

Transform the integrals by the substitutions

$$y = A\,t, \qquad x = [A - (n-1)\,a]\,s$$
$$d\,y = A\,d\,t, \; d\,x = [A - (n-1)\,a]\,d\,s$$

Then

$$P = \frac{[A - (n-1)\,a]^n \int_0 \int_0 \int_0 \dots \int_0 d\,s_1\,d\,s_2\,d\,s_3 \dots d\,s_n}{A^n \int_0 \int_0 \int_0 \dots \int_0 d\,t_1\,d\,t_2\,d\,t_3 \dots d\,t_n}$$

The conditions to be satisfied by the limits of integration in both numerator and denominator are now both the same, that is,

$$O < t < 1, \quad O < \Sigma\, s < 1$$

The integrals, therefore, cancel out, saving us the trouble of evaluating them, and we obtain

$$P = \left[\frac{A - (n-1)\,a}{A}\right]^n = [1 - (n-1)\,(a/A)\,]^n$$

TABLE I

AVERAGES (a) CORRESPONDING TO DEVIATION (d) PLUS AVERAGE (a) TO BE EXPECTED WITH DIFFERENT PROBABILITIES

Deviation Plus Average, $c = a + d$	P = 0.001	0.002	0.004	0.006	0.008	0.010	Deviation Plus Average, $c = a + d$
			Average = a				
1	0.001	0.002	0.004	0.006	0.008	0.010	1
2	0.045	0.065	0.092	0.114	0.133	0.149	2
3	0.191	0.243	0.312	0.361	0.402	0.436	3
4	0.429	0.518	0.630	0.709	0.771	0.823	4
5	0.739	0.867	1.02	1.13	1.21	1.28	5
6	1.11	1.27	1.47	1.60	1.70	1.79	6
7	1.52	1.72	1.95	2.11	2.23	2.33	7
8	1.97	2.20	2.47	2.65	2.79	2.91	8
9	2.45	2.72	3.02	3.22	3.38	3.51	9
10	2.96	3.26	3.60	3.82	3.99	4.13	10
11	3.49	3.82	4.19	4.43	4.62	4.77	11
12	4.04	4.40	4.80	5.06	5.26	5.43	12
13	4.61	5.00	5.43	5.71	5.92	6.10	13
14	5.20	5.61	6.07	6.37	6.60	6.78	14
15	5.79	6.23	6.72	7.04	7.28	7.48	15
16	6.41	6.87	7.39	7.72	7.97	8.18	16
17	7.03	7.52	8.06	8.41	8.68	8.90	17
18	7.66	8.17	8.75	9.11	9.39	9.62	18
19	8.31	8.84	9.44	9.82	10.11	10.35	19
20	8.96	9.52	10.14	10.54	10.84	11.08	20
21	9.62	10.20	10.84	11.26	11.57	11.83	21
22	10.29	10.89	11.56	11.99	12.31	12.57	22
23	10.97	11.59	12.28	12.73	13.06	13.33	23
24	11.65	12.29	13.01	13.47	13.81	14.09	24
25	12.34	13.00	13.74	14.21	14.57	14.85	25

Sampling Problem. As stated in the body of the paper, when the total number of calls under consideration is large as compared with the number of calls observed, the problem is essentially identical with the problem of drawing balls from a bag, the ball taken at each drawing being returned before the next drawing is made.

Assume, then, that n drawings from a bag containing an unknown ratio of white to total balls resulted in c white drawings and $(n - c)$ not white. In other words, assume that the observed frequency of white balls was (c/n). Considering the unknown ratio as a cause, let $W\,(x)$ be the *a priori* existence probability for the value x. The productive probability for the

value x, that is, the probability of obtaining c white and $n - c$ not white balls if the unknown ratio were x, is

$$\binom{n}{c} x^c (1-x)^{n-c}$$

where $\binom{n}{c}$ is a symbol for the combinations of n things c at a time.

By the sixth principle the *a posteriori* probability in favor of the unknown ratio having the value x is

$$P(x) = \frac{W(x)\binom{n}{c} x^c (1-x)^{n-c}}{\sum_{x=0}^{1} W(x)\binom{n}{c} x^c (1-x)^{n-c}} = \frac{W(x)\, x^c (1-x)^{n-c}}{\sum_{x=0}^{1} W(x)\, x^c (1-x)^{n-c}}$$

Therefore, the *a posteriori* probability that the ratio x does not exceed the value p_1 is

$$P(x > p_1) = \frac{\sum_{x=0}^{p_1} W(x)\, x^c (1-n)^{n-c}}{\sum_{x=0}^{1} W(x)\, x^c (1-n)^{n-c}}$$

When the total number of balls in the bag is large so that the difference between any two consecutive possible values for x is small, we may substitute integrals for the summations; giving

$$P = \frac{\int_0^{p_1} W(x)\, x^c (1-x)^{n-c} d\,x}{\int_0^{1} W(x)\, x^c (1-x)^{n-c} d\,x} \qquad (1)$$

Assume first that $W(x)$ is a constant b for $o < x < g$, where $g > p_1$. Then

$$P = \frac{\int_0^{p_1} x^c (1-x)^{n-c} d\,x}{\int_0^{g} x^c (1-x)^{n-c} d\,x + \int_g^{1} \frac{W(x)}{b} x^c (1-x)^{n-c} d\,x}. \qquad (2)$$

Now assume that

$$\int_g^1 \frac{W(x)}{b} x^c (1-x)^{n-c} d\,x\,,$$

is negligible compared with

$$\int_0^g x^c (1-x)^{n-c} d\,x,$$

and also assume that g, c and $(n - c)$ are such that approximately

$$\int_0^g x^c (1-x)^{n-c} d\,x = \int_0^1 x^c (1-x)^{n-c} d\,x$$

Then, finally,

$$P = \frac{\int_0^{p_1} x^c (1-x)^{n-c} d\,x}{\int_0^{1} x^c (1-x)^{n-c} d\,x} = \frac{(n+1)!}{c!\,(n-c)!} \int_0^{p_1} x^c (1-x)^{n-c} d\,x\,, \qquad (3)$$

This well known formula might have been obtained by assuming *a b* initio that $W(x)$ is independent of x. Particularly should it be noted that this independence is not identical with the assumptions made above.

In the applications which are here contemplated the values p_1, c and n are such that g need be but a small fraction of the range 0 to 1.

In the "Theorie Analytique" Laplace transforms (3) so that it can be evaluated in terms of the Laplace-Bernoulli integral

$$\frac{2}{\sqrt{\pi}} \int_0^k e^{-t^2} d\,t$$

where k is a function of p_1, c and n. This transformation is most valuable when p_1 is in the neighborhood of ½. For small values of p_1 the transformation which converts the binomial expansion to Poisson's exponential binomial limit is more appropriate and gives, writing $(n\,p_1) = a_1$,

$$P = \frac{1}{c\,!} \int_0^{a_1} y^c e^{-y} d\,y = P(c+1, a_1) \qquad (4)$$

SUPER-CONDUCTING COPPER

The production of copper that is capable of transmitting 13 per cent more current than present conductors was announced by Dr. W. P. Davey of the Research Laboratory of the General Electric Company at the December 31st meeting of the American Association for the Advancement of Science. These results were obtained with large single crystals of copper, the experimental production of which was recently accomplished in the Schenectady laboratory. Use of single-crystal copper is at present not commercially possible because of the delicacy of the crystals and because of the difficulties of manufacture, but from a scientific standpoint the results of these investigations are of great interest.

The single copper crystals were made by very gradually heating and cooling pure copper in an electric furnace. When molten metal is quickly cooled, very small crystals are formed; if the melt is cooled slowly, the crystals are larger. Employing the method of P. W. Bridgeman, Dr. Davey cooled the melt so slowly that only one crystal was formed, and that included all of the metal. By this method he was able to produce single crystals seven-eights of an inch in diameter and six inches long, or crystals of less diameter and greater length.

In a crystal, the atoms are built up in regular fashion. The crystals of copper for example, are made of very tiny cubes, with atoms of copper at the corners and centers of the faces of each cube. The large crystals grow in such a direction that the atoms are arranged in columns along the length of the crystal. It is this regular arrangement of the atoms which, it is believed, give to the single crystals their superior conductivity when compared with ordinary (polycrystalline) copper in which the crystals are small and the arrangement of the atoms more chaotic.

Storage Battery Electrolytes*

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Synopsis.—*Experiments have been in progress at the Bureau of Standards to determine quantitatively the effect produced by a wide variety of impurities on the rate of sulphation of storage battery plates. The method for making the determinations involves measuring the changing weight of the plates suspended in the solution. The various impurities are classified according as they affect the negative plates, the positive plates or both. A discussion is given also of certain combinations of impurities. Sodium and magnesium sulphates which are sometimes added to the electrolyte to "improve" the behavior of the battery are without effect on the rate of sulphation. It is important that some generally recognized specifications for storage battery electrolytes should be established.*

Introduction

THE satisfactory operation of a storage battery is in a large measure dependent upon the physical and chemical properties of the electrolyte which it contains. Within recent years storage batteries have come to be used under widely varying conditions of service, and millions of them annually pass into the hands of people who have no technical knowledge of their construction or adequate information with regard to the care which they should receive. Some of them are used at extremely low temperatures in airplanes and signal service while others are subjected to abnormally high temperatures in the tropics. Considering the diversity of the service which they have to perform, it is increasingly important that the physical and chemical properties of the electrolyte should receive more extended study.

For a number of months experiments have been in progress at the Bureau of Standards to determine quantitatively the effect produced by various impurities on the rate of sulphation of storage battery plates. The method which involves a determination of the weight of the plates while suspended in solution has been described in a previous publication.[1]

The results of experiments on a few of the impurities have been previously published in the JOURNAL of the American Institute of Electrical Engineers.[2]

TABLE I
ACCURACY OF MEASUREMENTS ON NEGATIVE PLATES
(Average of 14 experiments, pure electrolytes, 1.250 sp. gr. 25 deg. cent.)

Time (hours)	Average Gain in Weight (grams)	Probable Error of Average Value (grams)	Probable Error of Single Observation (grams)
50	0.69	0.03	0.15
100	1.44	0.06	0.24
200	2.68	0.09	0.33
300	3.87	0.13	0.41
400	5.03	0.16	0.50
500	6.08	0.21	0.60

*Approved by the Director of the Bureau of Standards.

†Both of The U. S. Bureau of Standards

1. Vinal and Ritchie. A new method for determining the rate of sulphation of storage battery plates. Bureau of Standards Technologic Paper No. 225 (1922).

2. Vinal and Altrup. *The effect of certain impurities in storage battery electrolytes.* JOURNAL A. I. E. E., Vol. 43, p. 313, (1924).

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-12, 1925.

In the present paper the results of experiments covering a wide range of impurities are given. The tables that follow give the quantitative relation between the amount of the various impurities which were added to the pure electrolyte 1.250 specific gravity, and the effects produced as judged by the change in weight of the plates.

Accuracy of Measurements

In the course of the experiments a number of determinations have been made of the rate of sulphation of storage battery plates in pure electrolytes having a specific gravity of 1.250 at 25 deg. cent. These may be considered as control experiments by which the effects produced by the impurities are to be judged. One control experiment was made with each group of five measurements. An analysis of these permits the computation of the probable error of the average value and the probable error of a single observation.

It is important to establish the range of the probable error in these computations. There are a number of impurities which produce little or no effect, and any definite statement that they do or do not produce an effect must be based upon a comparison with the normal values for plates in pure solutions to within the limits of the probable error.

Table I, for negative plates, and Table II, for positive plates, give the average gain in weight in pure electrolyte for these plates together with the probable error. In classifying the impurities according to the effects produced, the average value of the control experiments is given for comparison, except in Table VII where the measurements all belong to one group. For these, the value of the control experiment of this group is given.

Impurities Affecting the Negative Plates Only

The impurities which affect the negative plates only (Table III) may be divided into two classes:

a. Impurities which are deposited quickly in the metallic state upon the negative plates and produce appreciable gassing. These include platinum, copper and silver. A closed circuit exists between the underlying lead of the plate and the impurity which is deposited upon it. Lead sulphate is formed in proportion to the quantity of electricity flowing and the plate

gains in weight. Hydrogen is liberated at the surface of the impurity. The local action produced by these impurities proceeds at a fairly rapid rate until the ultimate capacity of the plate is exhausted. A considerable part of silver and copper, which was deposited on the plates as a spongy or tree-like mass, subsequently fell off so that the gain in weight of the plates represents chiefly lead sulphate. These impurities cannot be eliminated by changing the electrolyte in the battery, but their effect may in some cases be mitigated as Gillette[3] has shown. The results which are given in Table III show that platinum is one of the most deleterious of impurities. Extremely small amounts are sufficient to produce rapid sulphation of the plates. Copper produces less effect. These results have been abstracted from the previous paper by Vinal and Altrup, and in the case of copper a correction has been made for a misplaced decimal point in the former publication.

TABLE II

ACCURACY OF MEASUREMENTS ON POSITIVE PLATES

(Average of 17 experiments, pure electrolytes, 1.250 sp. gr., 25 deg. cent.)

Time (hours)	Average Gain in Weight (grams)	Probable Error of Average Value (grams)	Probable Error of Single Observation (grams)
50	0.34	0.03	0.12
100	0.51	0.04	0.17
200	0.66	0.06	0.22
300	0.86	0.08	0.30
400	1.05	0.10	0.35
500	1.15	0.10	0.32

TABLE III

LOCAL ACTION PRODUCED BY IMPURITIES AFFECTING ONLY THE NAGATIVE PLATES

(Results are expressed as the gain in weight of a single plate in grams, at intervals from 50 to 500 hours)

Impurity	Material Added	Percentage Impurity	Time in Hours 50	100	200	300	400	500
None	(Control experiments)	..	0.69	1.44	2.68	3.87	5.03	6.08
Platinum	$PtCl_4$	0.00001	0.7	1.4	3.0	4.8	6.8	8.4
Platinum	do	0.00003	13.2	19.3	26.1	29.9	32.4	34.2
Platinum	do	0.00005	27.4	28.1	28.8	29.2	29.3	29.5
Copper	$CuSO_4$	0.008	1.1	2.1	4.0	6.1	8.1	..
Copper	$CuSO_4$	0.04	7.3	10.7	15.6	19.5	23.5	..
Silver	Ag_2SO_4	0.1	13.5	18.6	24.0	..	..	..
Tin	$SnSO_4$	0.1	4.6	7.0	9.4	11.0	12.5	13.9
Tungsten	WO_3	0.003	0.3	1.7	5.3	10.0	15.0	20.0
Bismuth	Bi_2O_3	0.2	4.5	5.8	8.2	..	..	..
Sulphurous Acid	H_2SO_3	0.05	5.1	6.4	8.3	10.2	11.8	13.6
Sodium Bichromate	$Na_2Cr_2O_7$	0.05	3.3	5.2	8.4	11.4	14.1	..
Arsenic*	As_2O_3	0.001	1.3	2.6	4.8	6.9	8.8	10.9
Arsenic	As_2O_3	0.10	0.8†	..	..	..	..	..
Antimony	$Sb_2(SO_4)_3$	0.001	3.8	8.8	16.3	..	..	..
Nitrates	HNO_3	0.001	1.3	2.0	3.6	..	..	..
do	do	0.004	3.1	4.0	5.2	..	..	..
do	do	0.008	5.3	6.4	7.7	..	..	..
do	do	0.035	23.0	25.3	27.3	..	..	..

*These results are not as reliable as the others.

†At 55 minutes, plates gassing and solution turned brown, test abandoned.

3. *Trans.* Amer. Electrochem. Soc., 41, p. 217 (1922).

b. The second class of these impurities includes those chemical compounds which are reduced more slowly at the negative plates and result in little, if any, perceptible liberation of hydrogen. In some cases these impurities can be eliminated from a battery by replacing the electrolyte. For some of these, a quantitative comparison may be made between the calculated and observed changes in weight of the plate.

Bismuth presents an interesting example of the reduction produced at the negative plates accompanied by the deposit of the bismuth itself as a brown powder on the plate. Bismuth trioxide reacts with sulphuric acid to form bismuth sulphate and this, in turn, is reduced at the negative plate to bismuth with the formation of an equivalent amount of lead sulphate. For the 12.5 grams of bismuth trioxide, which were added to the solution, 24.4 grams of lead sulphate should be formed, and to this must be added the weight of the bismuth, 11.2 grams, deposited on the two plates in the solution making 35.6 grams as the calculated increase in weight of the plates. The amount actually observed was 33.6 grams. No appreciable effect was produced by the bismuth on the positive plates. The local action produced by the bismuth which is deposited in the pores of the negative plates is relatively slow, but the diffusion of the electrolyte into the plates is doubtless impeded with a consequent loss in the available capacity.

Antimony and arsenic, like bismuth, affect the negative plates, but are without apparent action at the positive plates. Antimony in particular produces a rapid discharge of the negative plates. The reactions of antimony and arsenic are probably analogous to those of bismuth, as the reduced material becomes visible after a short time. There is, in addition, a marked accelerating effect in the case of antimony, since the sulphation of the negative plates as measured by the increase in weight is much greater than would be calculated for the equivalent reduction of the antimony sulphate. This effect is less in the case of arsenic. The presence of either antimony or arsenic in the electrolyte is also detrimental because of the possible formation of stibine or arsine in the presence of hydrogen. These poisonous gases, escaping from the cells, become a serious hazard to those using the battery.

Nitrates which were added to the solution as nitric acid were reduced at the negative plate and produced a marked increase in the rate of sulphation. Even so small a quantity as 0.001 per cent produced a measurable result. Small quantities of nitrates probably do little permanent damage as they are gradually eliminated from the cell as oxides of nitrogen or reduced to ammonia. Nitrates were without effect in our experiments on pasted positive plates, but their use as corrosive agent in forming planté plates from sheet lead is, of course, well understood.

TABLE IV
LOCAL ACTION PRODUCED BY IMPURITIES WHICH AFFECT BOTH THE POSITIVE AND NEGATIVE PLATES
(Results are expressed as the gain in weight of a single plate in grams at intervals from 50 to 500 hours)

Impurity	Material Added	Percentage Impurity	Time in Hours 50	100	200	300	400	500
		(Positive Plates)						
None	Control experiments	..	0.34	0.51	0.66	0.86	1.05	1.15
Iron	$FeSO_4$	0.012	0.7	0.9	1.1	1.3	..	..
do	do	0.08	1.5	1.8	2.2	2.3	..	..
do	do	0.4	5.6	6.8	7.2	7.5	..	..
Manganese	$MnSO_4$	0.08	2.9	3.7	4.4	5.0	..	..
do	do	0.4	8.4	10.6	14.4	18.4	..	..
Chlorine	HCl	0.05	5.5	7.1	8.2	11.9	13.5	..
do	NaCl	1.00	23.7	25.4	26.0	26.2	..	..
		(Negative Plates)						
None	Control experiments	..	0.69	1.44	2.68	3.87	5.03	6.08
Iron	$Fe_2(SO_4)_3$	0.012	1.2	2.0	3.4	4.6	5.8	7.0
do	do	0.08	6.3	8.0	9.5	10.8	12.2	13.6
Manganese	$KMnO_4$	0.04	2.2	3.0	4.3	5.6	..	..
do	do	0.40	3.1	4.0	5.3	6.7	..	..
Chlorine	HCl	0.02	0.6	1.3	2.7	..	..	..
do	NaCl	1.00	22.0	27.1	30.2	32.7	..	..

Impurities Affecting both Positive and Negative Plates

In the previous paper,[4] details of the reactions of iron and manganese have been given. Iron is perhaps the most common impurity in storage battery electrolytes. It is oxidized at the positive plate and reduced at the negative plate without depositing on either *ad infinitum.* Since it stays in solution it can be eliminated by changing the electrolyte. Manganese is more detrimental to the positive plates than to the negatives. Its reactions are complicated and will not be repeated here.

Chlorine is a detrimental impurity for both the positive and negative plates, although in small quantities its effects are more pronounced on the positives. Chlorine is liberated at least in part from the cell, but others have stated that a portion of it is oxidized to perchloric acid and this remains in the electrolyte. The addition of sodium chloride to the electrolyte was tried because of the reactions which occur when sea-water may accidentally find its way into storage batteries used on ship-board.

Impurities Affecting Positive Plates Only

Impurities of this class are organic compounds. In our experiments with acetic acid, the effects produced were smaller than were anticipated, and several additional portions of acetic acid were added to the same jar at intervals without much effect as shown in the table.

Following the experiments with acetic acid a small group of separators which had not been previously used in batteries were extracted with sulphuric acid (1.250 specific gravity), and this solution was tried on both positive and negative plates. No appreciable effect on the changing weight of the negative plates was observed. However, the effect on the positive plates was striking. Separators which had been previously treated preparatory to their use in storage batteries produced smaller effects than similar separators which had not been so treated. These results led us to try dextrose, sucrose, invert sugar, and starch which produced effects of about the same amount. Tannic acid, however, produced only a very small effect as shown in the table. These results show that the separators have important effects which warrant further investigation.

Local Action Produced by Combinations of Impurities

Table VI shows the effects produced on negative plates by combinations of impurities which, taken singly, produced less effect than when present in combination.

Kugel[5] showed that the action of such combination as tungsten and copper exceeded materially the effects

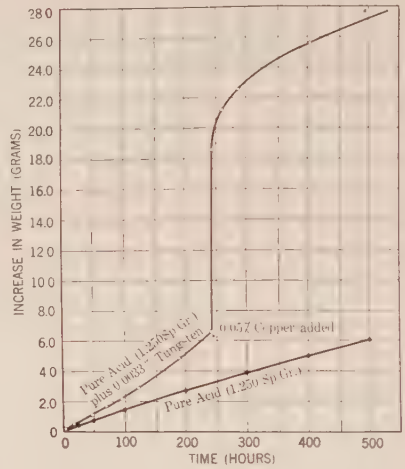

Fig. 1—Effect of a Combination of Copper and Tungsten on Negative Plates

of either of these materials singly. The extraordinary effect of adding a small percentage of copper to a solution containing a small percentage of tungsten is shown graphically in Fig. 1.

In addition to the experiments on tungsten and copper, combinations of copper with other impurities such as mercury, molybdenum, zinc, arsenic, and antimony were tried. In all of these cases it was found that the rate of sulphation of the negative plates was greatly accelerated. These results are significant in showing that it is important to limit the percentage of copper which may be present in the electrolyte to the smallest reasonable figure.

In explanation of this effect, Kugel has suggested that the polarization on the copper is decreased by the presence of tungsten. Scarpa[6] has advanced a similar explanation that the presence of tungsten lowers the overvoltage necessary for the evolution of hydrogen

4. Vinal and Altrup, *loc. cit.*

5. *Electrotech. Zeit.* 13, pp. 8, 19, (1892).

6. *L'Elettrotecnica 6*, p. 317 (1919).

on the surface of the copper. For this reason the local currents flowing between the copper and the underlying lead of the plate are greatly increased. This appears the most probable explanation and our results show that in addition to tungsten, which is an unusual impurity to find in storage battery electrolytes, there are a number of others much more likely to be present which may produce the same effects.

TABLE V

LOCAL ACTION PRODUCED BY IMPURITIES AFFECTING ONLY THE POSITIVE PLATES

(Results are expressed as the gain in weight of a single plate at intervals from 50 to 500 hours).

Impurity	Percentage Impurity	Time in Hours 50	100	200	300	400	500
None	(Control experiments)	0.34	0.51	0.66	0.86	1.05	1.15
Acetic acid	0.1	0.4	..	..	..	..	..
do	1.0	..	0.9	1.6	..	..	..
do	3.0	..	..	..	2.4	3.3	..
Separator extracts (treated)	..	3.2	5.2	7.7	9.4	..	..
Separator extracts (untreated)	..	8.9	13.5	18.6	21.1	..	..
Dextrose	1.0	23.2	26.3	27.2	..	..	..
Sucrose	1.0	23.6	26.7	27.6	..	..	..
Invert Sugar	2.0	23.6	26.4	26.8	..	..	..
Starch	0.5	11.5	20.3	25.1	..	..	..
Tannic Acid	0.10	0.6	1.1	1.9	2.6	..	..

In the course of our experiments combinations of tungsten with arsenic, antimony, and several other impurities were tried, but the tungsten produced no unusual effect except when in combination with copper.

Impurities Producing Little or No Effect

In the course of our experiments a number of impurities were tried which produced little or no effect on either the positive or negative plates. These included sodium, calcium, magnesium, aluminum, zinc, cadmium and mercury.

At various times sodium and magnesium sulphates have been suggested as an addition to sulphuric acid of the ordinary electrolyte to decrease the sulphation of the plates. Table 7 gives in detail the results which were obtained when these materials were added to 1.250 specific gravity electrolyte, and it will be seen that the agreement between the solutions containing these materials and the control experiment is within the limits of experimental error for both positive and negative plates. These results indicate that these substances are without effect on the rate of sulphation in concentrations up to 5 per cent, and no benefit is to be derived by adding them to ordinary solutions. Others have claimed that the presence of sodium sulphate and similar substances is harmful, resulting in the disintegration of the negative plates.

TABLE VI

LOCAL ACTION PRODUCED BY COMBINATIONS OF IMPURITIES AFFECTING THE NEGATIVE PLATES

(Each experiment was started with the first named impurity and then copper was added at the time shown)

Combination	Material Added	Percentage Impurity	Time of Adding Cu (hours)	Time in Hours 50	100	200	300	400	500
None (Control experiments)				0.69	1.44	2.68	3.87	5.03	6.08
{ Tungsten	WO_3	0.003	246	1.1	2.4	5.4	23.1	25.6	26.7
{ Copper	$CuSO_4$	0.05							
{ Mercury	Hg_2SO_4	0.01	145	0.8	1.7	31.6	31.8	31.0	31.2
{ Copper	$CuSO_4$	0.05							
{ Molybdenum	MoO_3	0.01	145	1.1	2.0	30.5	24.7	32.4	40.0
{ Copper	$CuSO_4$	0.05							
{ Zinc	ZnO	0.01	145	1.2	1.6	24.0	33.7	33.2	..
{ Copper	$CuSO_4$	0.05							
{ Arsenic	As_2O_3	0.001	145	1.0	2.0	23.2	25.8	28.0	29.2
{ Copper	$CuSO_4$	0.05							
{ Antimony	$Sb_2(SO_4)_3$	0.001	145	3.6	8.8	28.0	38.5	38.0	36.0
{ Copper	$CuSO_4$	0.05							

TABLE VII

EFFECT OF SODIUM AND MAGNESIUM SULPHATES

(Results are expressed as the gain in weight of a single plate in grams at intervals from 50 to 500 hours)

Impurity	Material Added	Percentage	Time in Hours 50	100	200	300	400	500
			(Positive Plates)					
None (Control experiment)	..	..	0.05	0.14	0.35	0.52	0.72	0.90
Sodium sulphate	$Na_2SO_4 \cdot 10H_2O$	2.0	0.05	0.1	0.3	0.4	0.6	0.7
do	do	5.0	0.2	0.3	0.5	0.7	0.8	1.0
Magnesium sulphate	$MgSO_4 \cdot 7H_2O$	2.0	0.1	0.2	0.3	0.5	0.7	0.8
do	do	4.0	0.2	0.3	0.5	0.6	0.7	0.9
			(Negative Plates)					
None (Control experiment)	..	..	0.80	1.52	2.97	4.25	5.53	6.82
Sodium sulphate	$Na_2SO_4 \cdot 10H_2O$	2.0	0.7	1.3	2.6	3.8	4.9	5.9
do	do	5.0	0.8	1.4	2.6	3.5	4.5	5.4
Magnesium sulphate	$MgSO_4 \cdot 7H_2O$	2.0	0.9	1.6	3.1	4.5	5.8	7.1
do	do	4.0	1.0	1.8	3.2	4.6	6.0	7.4

Suggested Specifications for Sulphuric Acid

Specifications for battery acid have been issued by many different agencies and a comparison of them shows wide divergence in the impurities which are listed and the maximum amounts which may be considered permissible. If suitable specifications for sulphuric acid for use in batteries can be formulated and receive general recognition, it is likely that they will find use also in other industries. The amount of concentrated sulphuric acid used per year for batteries in this country is probably in excess of 30,000,000 pounds.

If the amount of impurities allowed by the specifications is made too small, serious difficulty may be encountered in finding acid sufficiently pure to meet them. On the other hand the specifications must limit the impurities to amounts that are within the range for satisfactory battery operation.

Specifications are usually drawn to apply to the concentrated acid. If pure water is used to dilute this to the proper concentration for battery use the percentage of the impurity will be proportionately reduced. It is desirable that water of a high degree of purity be used, and no general statement as to the permissible use of natural water can be made for the reason that its purity varies from place to place and from one time of the year to another.

The following Table VIII, on the purity of sulphuric acid and solutions for battery use, has been taken from a recent book on storage batteries.[7] It is believed that this table is consistent with the results of this investigation and represents acid that can be readily procured. It may be desirable, however, to limit the amount of copper to a smaller percentage in view of the large local action which it produces when present together with certain other impurities shown in Table VI.

TABLE VIII
PURITY OF SULPHURIC ACID AND SOLUTIONS FOR BATTERY USE

	Concentrated Acid	Unused Electrolyte	Used Electrolyte
Specific gravity 60°F.	1.835	1.280	1.280
Per cent H_2SO_4	93.19%	36.8%	36.8%
Color	Colorless	Colorless	Colorless
Suspended matter	None	None	Lead compounds only
Platinum	None	None	None
Arsenic and antimony	Traces	Traces	Traces
Manganese	Trace	Trace	Trace
Iron	0.010%	0.004%	0.015%
Copper	0.005%	0.002%	0.005%
Nitrates and nitrites	Traces	Traces	Traces
Chlorides calculated as Cl	Trace	Trace	Trace
Organic matter	Trace	Trace	Trace
Sulphurous acid	Trace	Trace	None

The term "trace" is often used, but ill-defined. In general this term in these specifications should be regarded as meaning less than 0.001 per cent. Any standard specification of this character should include also a statement of the tests to be employed.

7. Storage Batteries, by Vinal, page 120 (1924).

Our experiments have shown that there are other impurities, in addition to those included in Table VIII, which produce effects in the storage battery. However, they are rarely present in sulphuric acid. It does not seem necessary to name them all, as a statement can be added calling attention to the fact that other impurities are absent.

The limits for impurities given in Table VIII are presented for discussion, and it is hoped that they may serve as a basis for specifications that will receive general recognition.

THE COST OF DAYLIGHT

Advancement in the production and use of artificial light can be emphasized in no better way than by the increasing tendency to depend upon it even in the daytime. A score of years ago artificial light was still a poor competitor with daylight. It was considered to be merely a feeble substitute by means of which the hours of industry or of recreation could be extended after a fashion. Today artificial light compares favorably with daylight in efficiency, does not always cost more and has many advantages in controllability and dependability.

Until recently the provision of ample daylight was a matter of habit in the design of buildings. Of course, architects knew it cost something to install and maintain daylighting equipment, but most persons even now are not conscious of this cost. Many charges may, however, be made against daylight and its total cost is startling. Men are likely to continue to use daylight where it can be obtained readily and without excessive cost and are likely also to install windows for the purpose of "letting vision out." But it is interesting to note that a growing recognition of the low cost, reliability and ease of control of artificial light is causing architects and others to scrutinize more carefully the cost and other characteristics of daylight.

On every hand in large cities there are places where daylighting equipment is not delivering natural light as satisfactory in quantity and distribution as it should be if its cost is to be justified. Although in special cases artificial light is now used exclusively, there are many cases where it would be best at the present time to effect a compromise. In other words, it would be better to utilize daylight only to the extent to which it can be obtained readily, at reasonable cost and with satisfactory results, and to invest the saving in providing better artificial light, which, when daylight fails entirely, must provide all the lighting. It is interesting to note that progressive architects are beginning to consider lighting problems on this basis. The lighting specialist will render a valuable service in bringing to the attention of architects and others this new viewpoint which efficient, dependable and controllable artificial light has made economically possible.

—*Electrical World.*

A Complex Quantity Slide Rule[1]

BY JESSE W. M. DuMOND[2]
Associate, A. I. E. E.

Synopsis.—*The need for a device to shorten numerical work with complex quantities is pointed out and a description is given of a slide rule in two dimensions devised to fill this need.*
* * * * *

THE principle of the ordinary slide rule can be extended into two dimensional space and applied to complex quantities.

Up to the present time, complex quantities have been employed almost exclusively for theoretical analysis and relatively little in numerical work. Formulas developed by means of complex quantities are generally split into components or otherwise transformed so that the numerical work is always performed with ordinary numbers. Unfortunately in many cases, formulas indeed very simple, when expressed as functions of complex quantities, have very much more elaborate expressions when thus transformed to adapt them to ordinary numerical work. An example of this is the propagation constant of a transmission line.

$$n = \sqrt{(R + j\,X)\,(G + j\,B)}$$

which becomes upon transformation

$$\frac{1}{\sqrt{2}}\left[\sqrt{(R^2 + X^2)\,(G^2 + B^2)} + (R\,G - X\,B)\right]^{\frac{1}{2}}$$

$$+\,j\,\frac{1}{\sqrt{2}}\left[\sqrt{(R^2 + X^2)\,(G^2 + B^2)} - (R\,G - X\,B)\right]^{\frac{1}{2}}$$

Here the advantage of treating the complex quantities as numerical entities and evaluating merely the formula

$$n = \sqrt{Z\,Y}$$

is evident. Seventeen numerical operations would thus be reduced to two, namely, one multiplication and one extraction of the square root.

To date, the use of complex quantities in arithmetical work has been hampered by the two following obstacles, both of which are removed by the complex quantity slide rule.

1. Frequently the known quantities are the phase-angle and modulus (effective value of current or voltage) whereas it may be necessary for calculation to transform this into a complex quantity in the component form. This requires a trigonometric transformation from modulus-phase-angle form to component form and frequently a second transformation of the final result from component form back to modulus-phase-angle form.

2. Ordinary numerical operations upon complex quantities are long. Multiplication and division are performed at present either by elementary algebraic methods, including multiplication of the conjugate of the divisor in division or by the modulus-argument method recommended by Kennelly, which necessitates trigonometric transformations. By the first method each multiplication requires four numerical operations of multiplication and two operations of addition or subtraction, a total of six operations. Each division requires two operations of squaring, three operations of addition or subtraction, four operations of multiplication and two operations of division, a total of eleven operations. By the second method each transformation from component form to modulus-argument form requires two divisions and looking in tables for the anti-tangent and the sine or cosine of one angle. Each transformation in the reverse direction requires looking in tables for the sine and cosine of one angle and two multiplications. When these transformations are made, two more operations one of multiplication or division, the other of addition or subtraction are necessary to effect a division or multiplication of the complex quantities. This is only slightly shortened by the use of ordinary logarithms.

It is very probable that complex quantities will become more and more useful to engineers and scientists as time goes on. It is also very likely that the most prominent obstacle to a wider application of them at present is precisely the above mentioned cumbersomeness which they possess in numerical work. With such an obstacle removed, many as yet undeveloped applications for them, would soon appear. In the domain of electricity alone, alternating current power transmission, telephony and radio, call for many applications of complex quantities. Their utility extends much farther offering as they do, very powerful methods of mathematical analysis applicable to a great variety of physical problems.

The Complex Quantity Slide Rule

It is possible to extend the principle of the ordinary or Mannheim slide rule to include complex quantities. The principle remains that of the graphical addition of logarithms, but the two degrees of freedom possessed by complex quantities, necessitates that the slide rule be extended over a plane surface.

In the ordinary engineer's slide rule the distance measured in appropriate units from the left extremity of the scale to any division on the rule is the logarithm of the number associated with that division.

In the complex quantity slide rule, the position of a point in a plane defined with reference to two rec-

1. This paper is an elaboration and an improvement of some ideas originally offered by the author as a thesis for the Master's Degree at Union College, Schenectady, New York.

2. Teaching Fellow, California Institute of Technology.

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tangular coordinate axes represents a complex quantity. This complex quantity is the logarithm of the complex quantity associated with the point.

Just as points on the ordinary slide rule are located by means of a set of non-uniform linear divisions, so on the complex quantity slide rule points are located by means of a system of curvilinear coordinates. These curvilinear coordinates consist of two mutually intersecting families of curves, a "real" family and an "imaginary" family, each curve having an associated number, the numbers ranging from one to ten. The curves are so arranged that the point at the intersection of any pair of curves referred to the rectangular reference axes graphically represents the logarithm of the complex quantity associated with that pair of curves.

The Curvilinear Coordinate System

Fig. 1 represents the system of curvilinear coordinates. The reference axes are shown by the heavy lines but since these are not necessary for the operation of the slide rule, they do not ordinarily appear upon it. The point P indicated in the figure is at the intersection of the curve + 3 of the real system and + 4 of the imaginary system and its coordinate distances from

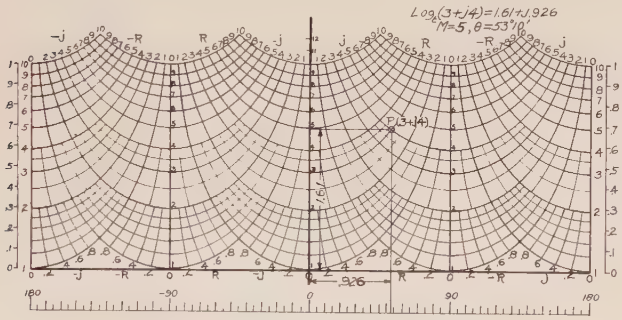

Fig. 1

the reference axes measured in appropriate units are 1.61 and 0.926 respectively. The Naperian complex logarithm of $(3 + j\,4)$ is $(1.61 + j\,0.926)$.

It will be noted that the system is divided into four similar patterns and that the numbers of the curves intersecting in each pattern differ only in algebraic sign. These signs are $(-,-)$ $(+,-)$ $(+,+)$ and $(-,+)$ naming the four patterns consecutively from left to right and giving in each case the sign of the "real" curve first. It is evident then that all complex quantities, whatever signs be associated with the real and imaginary components, have corresponding points on the system and each of the four patterns includes only those points whose corresponding complex quantities fall in a given quadrant in the ordinary clock or Argand diagram. In fact the horizontal distance measured in suitable units from the central vertical reference axis to any point in the system is equal to the argument or phase angle of the complex quantity associated with that point. Moreover the vertical distance measured again in suitable units up from the horizontal reference axes to any point in the system is the logarithm of the modulus of the complex quantity associated with that point. The reasons for these facts will be found in the appendix. Given a point on the system of curvilinear coordinates it is thus possible to read from the curves the "real" and "imaginary" components of the complex quantity associated with that point or to read the phase angle and modulus of the complex quantity by aligning the point with the horizontal scale of angles and with the vertical scale of moduli formed by the intersections of the curves with any one of the five vertical straight lines. The alignment is accomplished by a mechanical means to be described below.

The Curves as a Distorted System

The curvilinear coordinates may be derived by the proper distortion of a set of ordinary rectangular coordinates. This distortion will be described because it will serve the purpose of giving the shape of the curves and the operations they perform a clearer meaning.

If we subject a system of ordinary rectangular coordinates to a process of expansion and contraction such that all differential linear magnitudes at any point a distance r from the origin will change in the ratio $\frac{1}{r}$ then all parts of the system outside a unit circle about the origin will shrink and all points inside the unit circle will expand until the final shape assumed will be a cylinder of unit radius. The system of curvilinear coordinates shown is what would be obtained by developing this cylinder upon a plane.

Any straight line drawn on the original system of rectangular coordinates through the origin (this includes the two principle axes) will swing about an axis tangent to the unit circle where the line in question cuts the unit circle, very much as the ribs of an umbrella swing about the small circle to which they are attached while the umbrella is being closed. Meanwhile, the length elements of these lines will have shrunk for those parts originally outside the unit circle so that what were equal divisions will now have become much more crowded as the distance from the unit circle increases. Fig. 2 shows the initial and final states in this distortion process.

It will be clear from Fig. 2 that the principle axes of the original cartesian coordinates become the five vertical straight lines of Fig. 1, the end lines being coincident on the cylinder. It will also be clear why horizontal distances in Fig. 1 represent phase angles of complex quantities in the original system. Circles about the origin of the original cartesian coordinates as center become horizontal straight lines after distortion.

The horizontal separation of any two points on the rule measures the phase angle between the corresponding complex quantities.

Description of Rule in Simplest Form

In order to utilize the above described system of curves it is necessary to provide a means of graphically adding the complex logarithms which they serve to locate. This is accomplished by an element bearing these curves which is free to translate in any direction in a plane. This element shown at A, Fig. 3, occupies an initial position near the center of the board B. It can be repeatedly returned to this position by bringing certain fiducial marks f on the board and on the transparent insert of element A into coincidence. A second element C consisting of a jointed transparent celluloid arm bears a small black point which can be made to coincide with any point on the curvilinear chart A and will maintain the position of that point relative to the board B unchanged while the element A is undergoing translations.

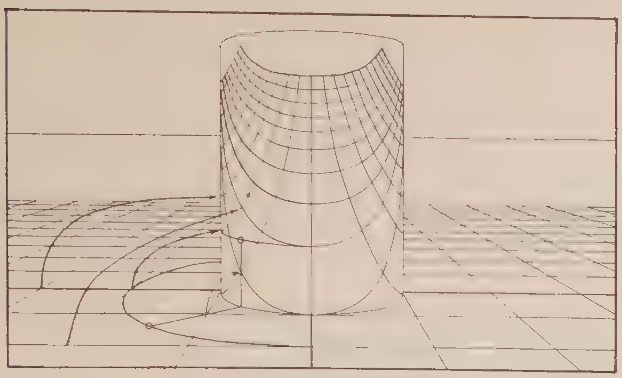

Fig. 2

The ordinary slide rule differs from the complex quantity slide rule in that the former is provided with both a stationary and a moveable scale while the latter has but one system of curvilinear coordinates. The operation of multiplication is performed as follows: With A in its initial position the pointer C is set to coincide with one of the complex quantities to be multiplied. The element A is then translated so as to bring $(1 + j\,0)$ or $(10 + j\,0)$ under the pointer C. The pointer C is then set to coincide with the second complex quantity to be multiplied. The product is read off by returning the element A to its initial position and reading the curves which now intersect under the pointer. The evaluation of a fraction containing factors in numerator and denominator can be rapidly accomplished by a similar process.

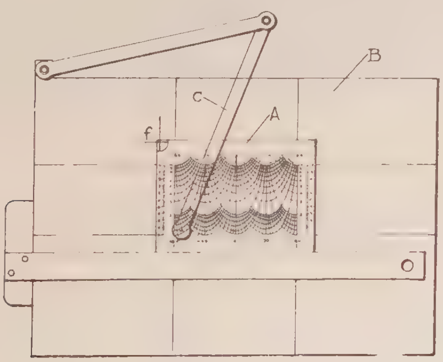

Fig. 3

Some care must be exercised as regards the decimal point in setting complex quantities on the rule. The curves are numbered up to 10 and in order to accomodate complex quantities whose components exceed 10 the decimal point is shifted the necessary amount in *both* components of the complex quantity. This shift is to be chosen so as to make the larger component fall between one and ten. It is important that *both* components should undergo the *same* decimal point shift.

The same difficulty of "running off scale" which occurs in the use of the ordinary slide rule appears in the complex quantity slide rule. This difficulty is avoided in a similar way and is completely absent in the improved form of the rule. It is evident that a displacement of either the rule or the pointer through a vertical distance equal to the distance on the rule from $(1 + j\,0)$ to $(10 + j\,0)$ affects only the decimal point of the result. A horizontal displacement through a distance equal to the horizontal length of the rule has no effect on the result since it is equivalent to rotating the complex quantity through a phase angle of 360. If then a point falls off scale it suffices to move either the rule or the pointer through one or both of the above displacements to bring it back on scale.

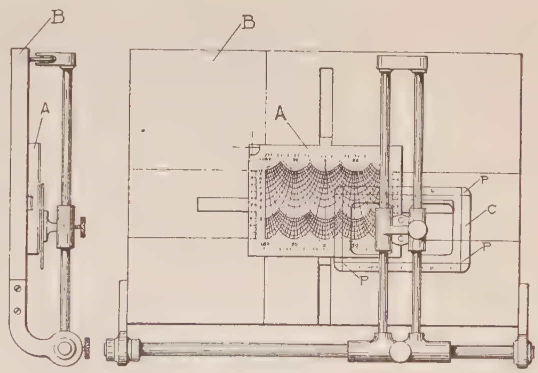

Fig. 4

Improved Form of Rule

Fig. 4 shows an improved form of the complex quantity slide rule.

The translatory movement of the chart A is guided by a cross arm device sliding in grooves in the top of the board B and the bottom of the element A.

The pointer is replaced by a celluloid rectangle C bearing two pairs of intersecting straight lines forming a rectangle whose length is equivalent to a displacement of 360 deg. and whose height is equivalent to a displacement from $(1 + j\,0)$ to $(10 + j\,0)$.

Any of the intersections or corners P of this rectangle may be used interchangeably as the fiducial point in

operations upon complex quantities since an interchange of corners only affects the position of the decimal point in the result. Since one of these corners *must* always be on the curvilinear chart there can be no difficulty from running off scale.

The straight lines on the "indicator" as the celluloid rectangle is called serve the purpose of aligning the point in question with a scale of phase angles provided on the top and bottom edges of the rule and also with the scales of moduli formed by the intersections of the curves with any one of the vertical straight lines. There are vertical scales of equal parts on either end of the rule which permit by means of these same lines on the indicator to read off the logarithms of the modulus of a complex quantity. In Fig. 4 the indicator is shown set on $(3 + j\,4)$, $M = 5$, $\theta = 53$ deg. 10 min.

The indicator is also provided with horizontal cosine or power factor scales which permit of reading directly the cosine of the angle between a point on the rule representing a current and a second point representing a voltage.

The horizontal and vertical scales of equal parts on the rule permit of reading directly the phase angle and the logarithms of the modulus of any complex quantity. A second complex quantity formed of these two readings with the angle as the imaginary component is the common logarithm of the original complex quantity. (In order to obtain the natural or Naperian complex logarithm the units would have to be reduced to radians and base ϵ logarithms.) If then any power or root of a complex quantity is desired it is sufficient to multiply or divide the readings of these two scales by the index of the power or root. The power or root is then read off the curvilinear chart at the point which is in alignment with the new dividend or multiplied readings on the scales.

It is thus possible by means of the complex quantity slide rule to perform multiplication, division, involution and evolution of numerical complex quantities as well as to find the logarithms of complex quantities. The time saved over what is required by ordinary longhand methods is very great. A single example will suffice to illustrate this.

Illustrative Example

The current that a certain generator must supply when a transmission line is short circuited at the receiving end is given by

$$I = 81200 \frac{(0.920 + j\,0.0356)\,(0.000445 + j\,0.002062)}{(0.0815 + j\,0.402)\,(0.32 + j\,0.77)}$$

Shifting the decimal points as explained above by equal amounts in one and the same complex quantity so as to bring the larger component in each case to a value between unity and ten gives

$$I = \frac{(9.20 + j\,0.356)\,(0.445 + j\,2.062)}{(0.815 + j\,4.02)\,(3.2 + j\,7.7)} \times 8.12 \times 10^2$$

Set the rule in the initial position. Set the indicator over the first complex quantity $(9.20 + j\,0.356)$. Move the rule so as to bring the indicator over the quantity $(0.815 + j\,4.02)$. Move the indicator over $(0.445 + j\,2.062)$. Move the rule so as to bring the indicator over $(3.2 + j\,7.7)$. Finally move the indicator over $(8.12 + j\,0)$. Return the rule to its initial position. The result found under the indicator is $(1.87 - j\,4.22)$.

The current is then

$$I = (1.87 - j\,4.22)\,10^2 = 187 - j\,422$$

The modulus or magnitude of the short-circuit current is read off where the horizontal line of the indicator crosses any one of the vertical lines of the rule. It is $M = 4.61 \times 10^2 = 461$ amperes. Without

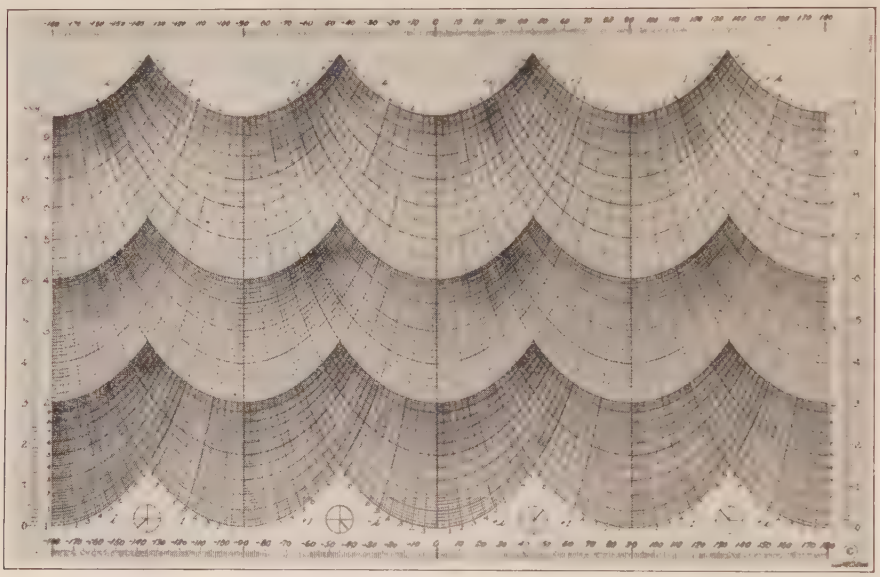

Fig. 5—Element "A" of Slide Rule

disturbing the indicator the phase angle may be read off. It equals – 66 deg.

In this problem the voltage was assumed to be on the axis of reals. The power factor is read off the cosine scale on the indicator as 0.41 and it is lagging since the phase angle of the current is negative.

Takes Care of Algebraic Signs

The work here accomplished with five settings of the rule would require some twenty operations with tables and logarithms or with an ordinary slide rule. Moreover the danger of mistakes in algebraic signs is largely eliminated because these are automatically cared for on the complex quantity slide rule if the settings are made correctly. The complex quantity slide rule goes definitely beyond the ordinary slide rule in this point of its ability to handle algebraic signs. Unlike the ordinary slide rule the value zero for either real or imaginary components appears on the rule. The complex quantity $(0 + j\,0)$ does not appear however.

Transcendental Functions

In many cases transcendental functions of complex quantities such as the hyperbolic and trigonometric functions are called for. Tables for such functions of a complex variable exist so that quantities taken from such tables could be employed directly on the rule. It is also possible to construct a complex quantity slide rule with interchangeable elements bearing curvilinear systems of coordinates adapted to perform operations with the transcendental functions. One difficulty, however, presents itself here. The network of curves shown in Fig. 1 if extended in all directions over an infinite plane so as to include all possible values of the complex variable, would be made up merely of an infinite number of repetitions of the pattern element as shown in Fig. 5, extending above, below and on all sides of it. It is this quality of multiplicity which makes it possible to operate with merely one element of the pattern, for homologous points in the different elements differ in absolute magnitude merely by multiples of ten and in phase angle merely by multiples of 360 deg. But in the case of a set of curvilinear coordinates adapted to some transcendental function of the complex variable, this convenient repetitive property no longer obtains. This places a rather awkward limitation on the utility of such special functional coordinates.

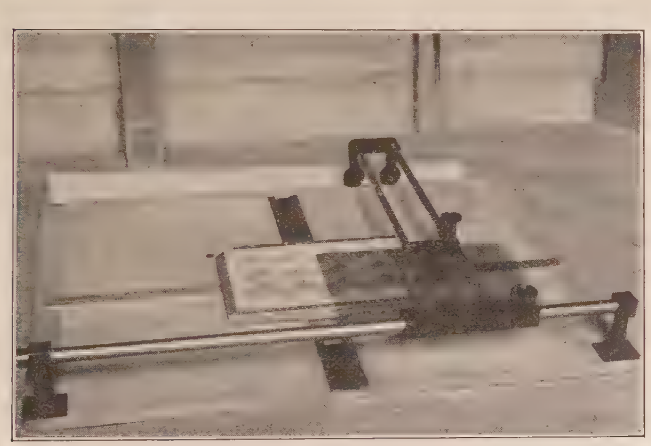

Fig. 6—Complex Quantity Slide Rule

Fortunately, in the case of the hyperbolic functions, the complex quantity slide rule affords another method without modification of the curvilinear coordinates. This is because the hyperbolic functions of a complex variable can be simply expressed as exponentials or antilogarithms. These antilogarithms can be taken from the complex quantity slide rule by a process the reverse of that described for finding logarithms. Thus $\sinh\,(a + j\,b)$, $\cosh\,(a + j\,b)$ and $\tanh\,(a + j\,b)$ can be found with the complex quantity slide rule without reference to tables. A detailed description of these special applications goes somewhat beyond the purpose of the present paper which is merely to introduce the device to the engineering fraternity. It is evident, however, that many formulas in use today in connection with alternating current work can be considerably simplified by modifications which would adapt them for use with the complex quantity slide rule. The ease with which ordinary analytic operations on complex quantities are performed with this device makes it feasible to compute infinite series and infinite products of a complex variable and thus to obtain numerical values of definite integrals and other functions heretofore practically prohibited by the labor of computation.

It is not to be supposed that the complex quantity slide rule is a *pons asinorum* to eliminate thinking. It requires perhaps even a clearer comprehension of complex quantities on the part of the operator than would be required by the older methods. It is a substitute for drudgery, not for intelligence.

Appendix

The logarithm of a complex quantity is itself another complex quantity. To find the components α and β of $\log\,(a + j\,b)$ let

$$\log_\epsilon\,(a + j\,b) = \alpha + j\,b. \qquad (1)$$

then

$$\epsilon^{\alpha + j\beta} = a + j\,b$$

$$\epsilon^{\alpha}\,(\cos\beta + j\sin\beta) = a + j\,b$$

Equating reals and imaginaries separately gives

$$\epsilon^{\alpha}\cos\beta = a$$

$$\epsilon^{\alpha}\sin\beta = b$$

Squaring and adding

$$\epsilon^{2\alpha} = a^2 + b^2$$

$$\alpha = \log_\epsilon \sqrt{a^2 + b^2} \qquad (2)$$

Dividing one by the other gives

$$\tan\beta = \frac{b}{a}$$

$$\beta = \tan^{-1}\frac{b}{a} \qquad (3)$$

so that we can write

$$\log_\epsilon (a + j\, b) = \log_\epsilon \sqrt{a^2 + b^2} + j \tan^{-1} \frac{b}{a} \quad (4)$$

The lower extremity of the central vertical line on the complex quantity slide rule is the origin point. The position of any point on the rule referred to vertical and horizontal cartesian coordinates through this origin point graphically represents the logarithm of the complex quantity associated with that point. The real curves are the loci of all points whose associated complex quantities have one and the same real value (and a variable imaginary value) and this value is the number printed beside the curve. The imaginary curves are the loci of all points whose associated complex quantities have one and the same imaginary value.

To find the equations expressing the loci, consider any point on the rule with which the complex quantity $(a + j\, b)$ is associated.

The coordinates of this point are

$$y = \log \sqrt{a^2 + b^2} \quad (5)$$

$$x = \tan^{-1} \frac{b}{a} \quad (6)$$

(The interchange of coordinates, y being taken for the axis of reals here is purely for convenience). The real loci are obtained by eliminating b between these two equations and the imaginary loci are obtained by eliminating a. This gives

$$y = \log a - \log \cos x \quad (7)$$

$$y^1 = \log b - \log \sin x \quad (8)$$

as the equations of the real and imaginary systems of curvilinear coordinates. The system is seen to be a conformal transformation of the type $W = \text{Log}\, y$. If the curves are plotted to scales of equal units for both x and y, all the intersections will be rectangular. This is not done in the actual rule as it yields a more convenient shape to compress the x-coordinates somewhat. It will also be noted that the curves consist of a characteristic part $(- \text{Log} \cos x)$ and an additive constant, $(\text{Log}\, a)$. In other words, all the curves on the rule are intrinsically identical and differ merely in their position.

From equations (5) and (6) it evident that at any point on the rule corresponding to $(a + j\, b)$ the y-coordinate is the logarithm of the absolute magnitude of $(a + j\, b)$ and the x-coordinate is the phase angle of $(a + j\, b)$. This explains the horizontal scale of phase angles. The method of reading the absolute magnitudes directly from the vertical scale formed by the intersections of the curves with any one of the vertical straight lines will be understood from the following.

Consider the equations (7) and (8) for the double system of curves already given. From (7) it appears that when, $a = o$, the equation of the "real" curve becomes

$$x = \pm \frac{\pi}{2} \quad (9)$$

and from (8) when, $b = o$, the equation of the "imaginary" curve becomes

$$x = 0,\ \pm \pi \quad (10)$$

In other words at these points respectively the real and imaginary systems have straight vertical loci. In each case the intersections of these straight vertical loci with the other system of curves may be found by substituting the values (10) into (7) and the values (9) into (8), giving

$$y = \log a \quad (11)$$

$$y' - = -\log - b \quad (12)$$

Thus it is seen that the y-coordinate of the point of inter-section of each of the curves with the vertical straight lines is in each case the logarithm of the number associated with that curve. Thus

$$y = \log a$$

The y-coordinate of any point on the rule is the logarithm of the absolute magnitude of the complex quantity associated with that point.

$$y = \log M$$

Hence, if the point is horizontally aligned with some point on a vertical straight line we have

$$\log a = y = \log M$$

$$a = M$$

so that by reading the value of a, on any vertical straight line at the same vertical height as the point in question the absolute magnitude of the complex quantity associated with that point is found.

Curvilinear System as a Distorted Cartesian System

Consider first the cartesian system, but divide it into infinitesmal elements by a system of radial straight lines and circles concentric about the origin. If we subject this to the distortion

$$d\, s' = \frac{d\, s}{r}$$

where r is the radial distance from the origin to the arbitrarily oriented linear element, $d\, s$, then it will be self evident that all of the concentric circles will assume unit radius, all of the elements of area previously included between adjacent radii and adjacent circles will become rectangles on a cylindrical surface and the radial lines will become elements of a cylinder of unit radius.

Consider a point which before distortion was at a radial distance, r, from the origin. All elements of this radius will shrink to $d\, r' = \frac{d\, r}{r}$. After distortion this point will be at a distance r' from the original unit circle on the cylinder.

$$r' = \int_{r=1}^{r=r} d\, r' = \int_{r=1}^{=r} \frac{d\, r}{r} = \log r$$

The distortion may be treated as follows.

The equations of the curves in the cartesian coordinates were

$$y = b, \qquad x = a$$

Now

$$d\,s = \sqrt{d\,y^2 + d\,x^2}$$

and

$$d\,s' = \frac{d\,s}{r} = \frac{\sqrt{d\,y^2 + d\,x^2}}{\sqrt{x^2 + y^2}} = \sqrt{d\,x'^2 + d\,y'^2}$$

$$d\,x'^2 + d\,y'^2 = \frac{d\,x^2 + d\,y^2}{x^2 + y^2}$$

This is the only condition imposed by the distortion. We may choose the value of either $d\,x'$ or $d\,y'$ in any arbitrary way compatible with the distortion. Thus we may say

$$d\,y' = \frac{d\,r}{r} = \frac{d\sqrt{x^2 + y^2}}{\sqrt{x^2 + y^2}} = \frac{x\,d\,x + y\,d\,y}{x^2 + y^2}$$

Then

$$d\,y'^2 = \frac{(x\,d\,x + y\,d\,y)^2}{(x^2 + y^2)^2}$$

$$d\,x'^2 = \frac{d\,x^2 + d\,y^2}{x^2 + y^2} - \frac{(x\,d\,x + y\,d\,y)^2}{(x^2 + y^2)^2}$$

$$d\,x'^2 = \frac{x^2\,d\,y^2 - 2\,x\,y\,d\,x\,d\,y + y^2\,d\,x^2}{(x^2 + y^2)^2}$$

$$= \left(\frac{x\,d\,y - y\,d\,x}{x^2 + y^2}\right)^2$$

$$d\,x' = \frac{x\,d\,y - y\,d\,x}{x^2 + y^2}$$

Integrating

$$y' = \int \frac{x\,d\,x + y\,d\,y}{x^2 + y^2} + c, \quad x' = \int \frac{x\,d\,y - y\,d\,x}{x^2 + y^2} + c_1$$

for the curve

$$x = a, \quad d\,x = 0$$

$$y' = \int \frac{y\,d\,y}{a^2 + y^2} + c, \qquad x' = \int \frac{a\,d\,y}{a^2 + y^2} + c_1$$

$$y' = \log\sqrt{a^2 + y^2} + c, \quad x' = \tan^{-1}\frac{y}{a} + c_1,$$

$$\text{or } y = \log a - \log\cos x'$$

similarly for the curve

$$y = b, \quad d\,y = 0$$

$$y' = \log\sqrt{b^2 + x^2} + c, \quad x' = \tan^{-1}\frac{b}{x} + c_1,$$

$$\text{or } y' = \log b - \log\sin x'$$

if we choose c and c_1 arbitrarily equal to zero which amounts to fixing the origin point.

ARTIFICIAL ILLUMINATION OF POULTRY HOUSES FOR WINTER EGG PRODUCTION

The fact that the use of artificial light has been found in some instances, to stimulate winter egg production by as much as 70 per cent, has brought up the question as to what intensity is conducive to maximum production. The answer to this was obtained only after an extended investigation covering a period of two years. As a result of observations carried on jointly by the Department of Rural Engineering and the Department of Poultry Husbandry of the New York State College of Agriculture, it was found that the illumination necessary for active feeding should be in the neighborhood of one foot-candle. It was also discovered that besides the illumination on the feeding area, it was quite essential that there be sufficient direct light on the perches, in order that the birds would not have a tendency to roost there.

The use of a standard 40 watt, clear, Mazda B lamp, with cone-shaped reflectors, 16 in. in diameter at the base, by 4 in. high, with reflecting surface of aluminum bronze, hung six feet above the floor and spaced 10 feet apart was found to meet the requirements.

In lighting the pen, the poultryman has at his disposal three different types of light; extending the morning light, morning and evening light, or evening light alone.

So far as production goes, each method produces satisfactory results if other conditions of management are correct. Artificial morning light is used extensively, because it is the cheapest to install, and lends itself readily to inexpensive, automatic control by a time clock. However, the extra cost of installation for evening light is small, and with this installation any method of handling may be practised. Whatever the method, the bird should have a 12 or 13 hour day.

It has been determined that the lights may be turned on suddenly without affecting the birds, but that turning the lights off suddenly makes it very difficult for the birds to go to roost.

In order to bring about a practical way for dimming the lights, the poultryman has at his disposal three different wiring systems, which are commonly known as:

1. The resistance unit system.
2. The two circuit system.
3. The series parallel system.

A full explanation of each system being given in the test.

In the concluding pages of the bulletin, data is given as to where control devices may be obtained, and the matter of the operation of poultry lighting with reference to the farm lighting plant is taken up. The bulletin is profusely illustrated with cuts which bear out the statements contained in the text, and really tends to prove beyond a doubt the outstanding features of the bulletin. Wiring diagrams for all of the above mentioned circuits are also shown in a very simple and practical manner.—*Cornell Extension Bulletin No. 40.*

Our Annual Waste of Research Material[1]

BY J. B. WHITEHEAD[2]
Fellow, A. I. E. E.

As subjects for my brief address, two thoughts have suggested themselves, either of which I believe is germane to the purposes of the Foundation and of this meeting.

Electrical Insulation

The Committee on Research of the American Institute of Electrical Engineers is devoting practically its entire attention to the problem of electrical insulation. Electrical engineers everywhere realize the importance of this problem, and I believe that others will have no difficulty in appreciating its importance when I say: that in these days of large units, high voltage, and demand for the utmost of reliability, insulation of electrical equipment is its weakest and most uncertain link; that the laws of electric breakdown, energy loss, and power factor, of fabricated insulation are almost entirely unknown; that there are no satisfactory theories of dielectric behavior; that physicists, after fifty years of study, have apparently abandoned this field of investigation; and that electrical engineers are unable to design insulation except in the most approximate way, and then with a large element of uncertainty as to its performance. The present efforts of the Committee on Research are directed towards a collection and coordination of the vast amount of important work already done, with a view to proposing a systematic plan of experimental attack. This preliminary task alone is of vast magnitude. Two principal conditions combine to make its progress slow. The first is the fact that those who are engaged are busy men, and the Committee's work must usually take a secondary, if not a very minor place, in their programs. The second condition is the very limited number of available men who are capable of making such a critical survey and of sifting and coordinating the important data.

Now I feel sure that this general problem could be made the basis of a powerful appeal to this Foundation for its interest and support in the field of electrical engineering research. Perhaps I am losing an opportunity in not attempting such an appeal. I prefer however to leave such a direct appeal to a later date, and to devote the brief time still remaining to me to my second thought, which has already been indicated in calling your attention to the small number of competent men available for the problem of insulation. The situation in the electrical field in this regard cannot be unique, and it seems to me to be a matter of such general importance as to merit the serious consideration, not only of this Foundation, but of all bodies interested in the promotion and advance of engineering research.

Research Workers

The successful and useful research worker must be trained thoroughly not only in the history and principles of his particular field, but also in the traditions and methods of scientific research. Our universities and colleges are the obvious, in fact the only agents, whose special purpose it is to offer this training. Yet one of the most noticeable features of our present system of education for engineering, is the almost negligible number of young engineers who proceed beyond the four-year bachelor's degree, into the advance training which is the first prerequisite for a research worker. The explanations are more or less obvious. The principal duty of our schools of engineering is to turn out large numbers of young men of reasonably good training for the every-day business of our various technical activities. My comments must not be understood as losing sight of the importance of this duty. The point I make is that the attractions in industrial opportunities, the active solicitation by the industries of these young men approaching their first degree, the fact that so many of them see an immediate opportunity to earn their living, all combine to surround the opportunities and attractions of advanced scientific training with an atmosphere of remote uncertainty, with the result that those going forward are extremely few, and with a further consequence that in only a few of our schools of engineering are graduate courses and training for research available, of such a character and on such a scale as to appeal to the four year student just graduating.

The young men leaving even the best of our schools of engineering at the end of four years are only partially trained, and only in single exceptional cases are they likely to develop into resourceful and creative research workers. They are insufficiently versed in the history, the theory, and in the technique, and in most cases have never even breathed the atmosphere, of scientific research.

The bulk of important engineering research today is inspired, directed, and often actually performed, by men of advanced scientific training, most often trained in the field of pure science. It has been stated, and with some force, and with the support of many brilliant examples, that training in pure science is the sufficient if not the best, training for engineering research. But can we engineers admit this? We cannot blind ourselves to the facts that our physical and chemical research laboratories give their first interest to the

1. Read at meeting of Engineering Foundation, December 16, 1924.

2. Dean, School of Engineering Johns Hopkins University.

3. For references see Bibliography.

advance of pure knowledge and theory. That they rarely, if ever, reach into the applied field, either in instruction or experimental research, and too often they are actually indifferent to its problems. On the other hand, problems in the field of engineering involve quantities, magnitudes, ranges of value, and methods of measurement and control rarely touched in our laboratories of pure science. It must be admitted that something more than training in pure science, and certainly something more than normal undergraduate engineering training, is needed for the field of engineering research. Do we not need men trained in both fields, that is, in the complete theory of a particular specialty, in complete knowledge of its application, in the methods of scientific research, and in an atmosphere sympathetic to research?

If these things are so, are we not in the position of advocating the importance and the support of engineering research, and yet neglecting a factor most essential to our great purpose. Is there not here an opportunity, nay, a duty, for such foundations as this? Or is it that these things are already clearly before our minds and that we hesitate at corrective measures by reason of the complexity and magnitude of the problems? I cannot think the latter, for while the influences and conditions leading to the present situation are widespread and difficult to reach, and while there is no obvious corrective measure promising immediate results, I nevertheless believe it possible to state a simple fundamental corrective principle, and to mention at least two methods of its application.

The opportunities and attractions in the field of engineering research must be brought more prominently before the student in his undergraduate years. This is a duty not only of the school of engineering, but also of technical industry. At present the latter is so blind to the value of this policy that its agents actively compete for the flower of the undergraduate classes and literally snatch them into active work after the bachelor's degree. The value and importance of research is now generally recognized in industry, but industry needs yet to recognize its own interest in "selling" research to a selected few young men. Industry can do this by showing the opportunities in research, by assisting and encouraging, by promise of preferred treatment, those who advance to the master's and doctor's degrees, and by returning to college those who develop the taste and aptitude in their early professional years. There is already some evidence of action of this character in the establishment of research fellowships, and other similar means, for enabling the young man to continue into the graduate years. It is an important and practical method, for generally the student of engineering is at the end of slender resources when taking his bachelor's degree. Concerted action on the part of a few large industries in accordance with these suggestions would not only remove one of the greatest of present deterrent causes, but would go far to stimulate the interest of the undergraduate in the field of research.

Naturally the school of engineering has just as clear a duty in this matter, a duty all the greater because of the wider opportunity for exerting it. If, during his undergraduate years, the student can see research in progress in the graduate school, if he knows that faculty and advanced students are devoting their best efforts to experimental investigation, if he hears these things described in class room and seminary, there is certain to be borne in upon a favored few the knowledge that here is an opportunity not only for a high type of service, but for work of unbounded interest and charm. We probably now have a sufficient number of graduate schools to meet even an expanded demand for research engineers of advanced training. But probably in no single one of them are the ideal conditions just outlined completely realized. Schools of engineering work to rigid budgets and it is difficult to convince governing boards to appropriate beyond the heavy demands of the large and important problems of undergraduate instruction. Teaching staffs are over burdened with the overwhelming demands of undergraduate instruction, and too often are themselves lacking in training and in the vision of research. The need here is for the upbuilding and expansion of a few graduate schools, and an emphasis on the importance of advanced formal training. Endowed research professorships or even fellowships in these schools, working in contact with industry, the national engineering societies, and such bodies as this one, would I believe have a far reaching influence and value for engineering research.

I have brought to your attention a matter which has been borne in upon me through many years of teaching and research. Doubtless there are other corrective measures than those I have suggested and certainly much more might be said on the subject. My purpose will have been achieved if The Engineering Foundation will give the question its consideration and particularly if it should be led to call attention in some public way to our annual waste of promising research material.

CABLE RESEARCH

A number of companies operating paper insulated cables at high voltage have recently observed a peculiar "cheese" or waxlike formation in cables which have been in operation for some time. In many cases this formation accompanies cable failures, but so far there is no definite proof that it is a cause of failure. The Research Bureau of the Electrical Engineering Department of the Brooklyn Edison Company has been making an intensive study of this phenomenon to determine its nature and significance.

In a number of samples of "cheese" removed from cables near the point of failure, it has been possible to detect impurities of a quite unexpected nature. Experiments are now in progress to determine what part these impurities play in the formation of the "cheese" and what effects it may have on the breakdown of the cable.

The Thermal Time Constants
of Dynamo-Electric Machines

BY A. E. KENNELLY†
Fellow, A. I. E. E.

Review of the Subject.—*Considering the thermal behavior of a dynamo-electric machine intended for continuous service, its acceptance tests require, at present, only a limiting temperature elevation under a continuous rated load. For the intelligent operation of a machine after it has been put in service, additional information is desirable concerning its thermal behavior under changes of load. This subsidiary thermal information concerning a machine with a continuous rating may consist of (1) its final temperature rise under some steady load other than its rated load, such as either 75 per cent or 125 per cent of the rated load, and (2) its thermal time constant.*

The thermal time constant of a machine, assumed as conforming strictly to an exponential law of temperature rise above a constant ambient temperature, after being transferred suddenly from one steady load to another, is taken as the time required to attain $1-\epsilon^{-1}$ or 63.2 per cent of the final temperature change. This may be called the exponential thermal time constant. This is a fundamentally scientific quantity; but is very awkward to remember or to explain to a person not well versed in the mathematical theory of the subject.

It is recommended in the paper that for all practical engineering work, a new time constant called the binary time constant be used. It would correspond to the "Period," or "Half-value period," already used in the Science of Radio-activity and in measurements of Radio active decay. A binary time constant is that time in which a machine, assumed as conforming to an exponential law of temperature change, after being suddenly transferred from one steady load to another, attains one half of the final temperature change (50 per cent). In two binary time constants, it will then attain ¾ (75 per cent) of the final temperature change, in three of them ⅞ths (87.5) and so on. This is an easy relation to remember and explain. A binary thermal time constant may be taken, for practical purposes, as 70 per cent of the classical exponential time constant. It is more strictly 69.32 per cent.

Although dynamo machines do not rigidly follow an exponential law of temperature change, for reasons discussed, yet for many purposes the deviation therefrom may be ignored. It is recommended that the binary time constant of all such machines may be adopted, where practical, for industrial use.

In rotating machines, there are two thermal time constants, the constant-loss time constant, and the variable-loss time constant. The latter, expressed as a binary constant, is the practical one presenting itself for use.

The binary thermal time constant has also useful applications in correcting the final ambient temperature during a continuous-load test, when the ambient temperature has been observed to change.

It is proposed to discuss the nature, applicability and advantages of the thermal time constants of dynamo machines, from an engineering standpoint. Although, broadly speaking, the subject is not new, it is believed that certain new branches of it are here presented for consideration.

The Transient State of Temperature Elevation

When the output of a machine is changed abruptly from one steady value to another, or when at constant output the ambient temperature changes quickly from one steady value to another, the thermal state of the machine changes slowly from the initial condition to a final condition, corresponding to the impressed change. The transition is a transient phenomenon; although it may require many hours to complete, within the limits of engineering measurements, and theoretically the full transition requires infinite time. From an engineering viewpoint, the temperature change in the machine is a transient. It has long been known[1] that under the assumed limitation of constant losses in the machine during the transition, the transient is a simple exponential transient, like that of the current strength in a simple continuous-current circuit containing both resistance and inductance. It has recently been shown by P. Girault[2] that the temperature transient is still simply exponential when the iron losses are constant, but the copper losses increase according to the resistance temperature co-efficient of the windings.

It is proposed to carry this proposition here one stage further, and to show, on the assumption that the iron losses also follow a straight line law of change from the initial to the final temperature, the change in temperature of the machine will remain a simple exponential transient, with a time-constant curve.

Fig. 2 indicates a simple circuit of resistance R, and non-ferric or air-cored inductance $\mathfrak{L}$, carrying a steady initial current of I_1 amperes from a storage battery of negligible resistance, through a recording oscillograph O. A switch S enables the e. m. f. of the battery E to be suddenly increased from 20 to 50 volts, or suddenly diminished from 50 to 20. A sensitive relay A, automatically inserts a protective resistance r in circuit with the upper part of the battery, when the switch S places that battery on short-circuit.

1. "Temperature Curves and the Rating of Electrical Machinery." R. Goldschmidt, *Jour. I. E. E.* London. March, 1905. Vol. 34, pp. 660-691.

"The Heating and Cooling of Electrical Machinery," P. Grice, *Jour. I. E. E.* London. Nov. 1912, Vol. 51, 1913, pp. 840-851.

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Abridgement of paper to be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 9-12, 1925. Complete copies to members on request.

2. "Sur l'échauffement d'un organe de machine électrique soumis à des pertes dans le fer constantes, et à des pertes par effet Joule," P. Girault, *Rév. Gén de l'Electricité.* 2nd & 9th Dec. 1922, Vol. XII, pp. 873 and 874; also 28th July and 4 Aug. 1923, Vol. XIV, pp. 115 and 147.

Exponential Time Constant τ_ϵ

If I_1 be the initial steady current strength (amperes) and I_2 the final steady current, after throwing the switch at time $t = 0$, the transient current i at any intermediate instant, according to well-known principles, is

$$i = I_2 + (I_1 - I_2)\,\epsilon^{-\frac{t}{\tau}} \qquad \text{amperes} \qquad (4)$$

where ϵ is 2.71828 . . ., the Napierian base and

$$\tau = \mathfrak{L}/R = \tau_\epsilon \qquad \text{seconds} \qquad (5)$$

a time constant, equal to the inductance in henries divided by the resistance in ohms, which is 0.005 second

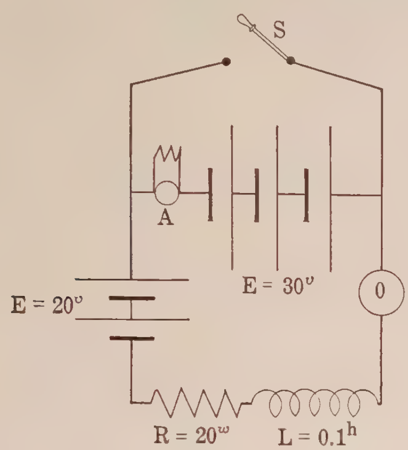

Fig. 2—Simple Continuous-Current Circuit for Displaying a Simple Exponential Transient

in the case of Fig. 2, and which we may call an *exponential time constant*, denoted by the symbol τ_ϵ, to distinguish it from other time constants to be considered later.

Fig. 3 indicates the transient current curve $A\ B\ C \ldots N\ O\ P$, on opening switch S, as we might expect to find it recorded by the oscillograph O Fig. 2. The current starts at $I_1 = 1.0$ ampere for $t = 0$. After the lapse of τ_ϵ, one exponential time constant, it has reached C, at 1.948 amperes, having risen 0.948 out of the total change

$$\Delta = I_2 - I_1 = 1.5 \qquad \text{amperes} \qquad (6)$$

that it has to cover. The fraction $0.948/1.5 = 0.6321$, may be called the *attainment*, at the point C considered. The remainder Cc,

$$\delta = I_2 - i = 0.552 \qquad \text{amperes} \qquad (7)$$

is what is left to be overcome. The fraction

$$\frac{\delta}{\Delta} = \frac{0.552}{1.5} = 0.3679$$

may be called the *deficiency* at this point. At any instant, the sum of the attainment and the deficiency is unity. At C, one exponential time constant from A, the deficiency is always $1/\epsilon$, or 36.79 per cent, and the attainment 63.21 per cent.

at $t = 2\,\tau_\epsilon$, or point E in Fig. 3, the deficiency

$$\frac{\delta}{\Delta} = \frac{e\,F}{e\,e'} = \frac{0.203}{1.5} = 0.1353 = \epsilon^{-2}$$

and the attainment is $1 - \epsilon^{-2} = 0.8647$.

At $t = 3\,\tau_\epsilon$, or point I in Fig. 3, the deficiency

$$\frac{\delta}{\Delta} = \frac{i\,I}{i\,i'} = \frac{0.0747}{1.5} = 0.0498 = \epsilon^{-3}$$

and the attainment is $1 - \epsilon^{-3} = 0.9502$. This is probably the simplest statistical relation to express, or to remember, concerning an exponential time constant; *i. e., that in three of them, the deficiency is very nearly 5 per cent.*

It is to be noted that at any point of the curve, such as C, Fig. 3, the tangent $C\,e$ cuts the final current line I_2, at a time distance beyond c, of $c\,e$, equal to the exponential time constant. Consequently, if we know the final steady current I_2, and can trace the curve of the transient at any point with sufficient precision to draw the tangent, we can measure the time constant τ_ϵ graphically, the subtangent on the final line I_2 being constant, and equal to τ_ϵ.

We may rewrite equation (4) in the form

$$i = I_2 + \Delta\,\epsilon^{-\frac{t}{\tau_\epsilon}} \qquad \text{amperes} \qquad (8)$$

or in the case of Fig. 3

$$i = 2.5 - 1.5\,\epsilon^{-\frac{t}{0.005}} \qquad \text{amperes} \qquad (9)$$

Because $I_1 - I_2$ is negative, we apply the negative sign to Δ.

The exponential time constant is, from a mathemat-

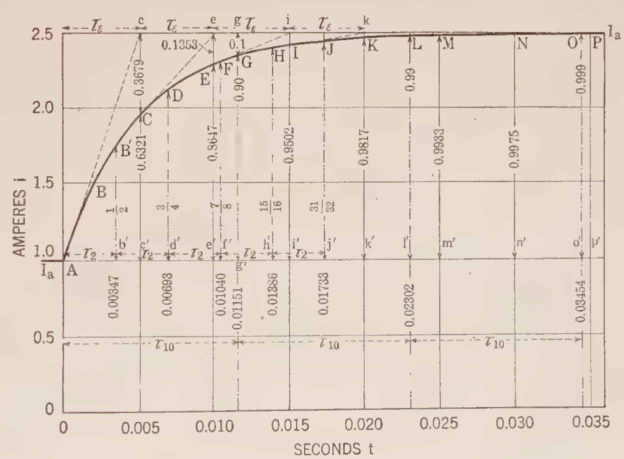

Fig. 3—Simple Exponential Transient of Current Increase from $I_1 = 1.06$, $I_2 = 2.5$, $\tau_\epsilon = 0.005$, $\tau_2 = 0.00347$, $\tau_{10} = 0.01151$ Second

ical standpoint, the fundamental property of the simple exponential transient; but it is awkward to employ practically, or to explain in simple terms. When we say that after the lapse of one exponential time constant the deficiency is 1/2.71828, we do not convey a simple conception, except to a person familiar with the mathematical subject of exponentials.

Binary Time Constant τ_2

We may, however, restate (8) as follows

$$i - I_2 = \delta = \Delta\,\epsilon^{-\frac{t}{\tau_\epsilon}} \qquad \text{amperes} \qquad (10)$$

$$\frac{\delta}{\Delta} = \epsilon^{-\frac{t}{\tau_\epsilon}} = \epsilon^{0.69315 \times \frac{-t}{0.69315\tau_\epsilon}} \text{ deficiency ratio} \quad (11)$$

But

$$\epsilon^{0.69315} = 2 \quad (12)$$

so that

$$\frac{\delta}{\Delta} = 2^{-\frac{t}{0.69315\tau_\epsilon}} = 2^{-\frac{t}{\tau_2}} \text{ deficiency ratio} \quad (13)$$

where

$$\tau_2 = 0.69315\, \tau_\epsilon \quad \text{seconds} \quad (14)$$

That is, we may transfer the deficiency from the Napierian base ϵ to base 2, and substitute for the exponential time constant a new time constant τ_2, which is very nearly 70 per cent of τ_ϵ. This new time constant τ_2 may be called, for distinction, the[3] *binary time constant.* The binary time constant would then correspond to what has already been known for some years as the "Period," or "Half-value period," in the science of Radio-activity, and in the measurement[4] of radio-active decay.

In Fig. 3, the time $A\,B' = 0.00347$ second, is shown as equal to the binary time constant τ_2. At the time $t = \tau_2$, the current will have reached B', and the deficiency δ/Δ at this moment is 2^{-1} or ½. The attainment is likewise ½. Again, at $t = 2\,\tau_2 = 0.00693$ second $= d'$, the deficiency is $2^{-2} = ¼$, and the attainment $1 - 2^{-2} = ¾$. Similarly, at $t = 3\,\tau_2 = 0.0104$ $= f'$, the deficiency is $2^{-3} = ⅛$, and the attainment $1 - 2^{-3} = 7/8$, corresponding to point F. Five binary time constants are marked on Fig. 3, as far as j', where the deficiency is $2^{-5} = 1/32$, and the attainment 31/32.

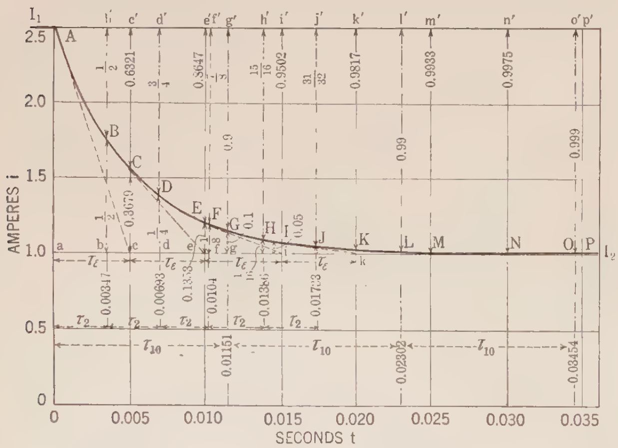

Fig. 4—Simple Exponential Transient of Current Decrease from $I_1 = 2.5$ to $I_2 = 1.0$, $\tau_\epsilon = 0.005$, $\tau_2 = 0.00347$, $\tau_{10} = 0.01151$ Second

The binary time constant τ_2 is just as sound mathematically as the fundamental exponential time constant τ_ϵ, and is always approximately 70 per cent of the latter. The binary time constant has the practical advantage that it is easier to remember and explain. In τ_2, the attainment and the deficiency are both ½, or 50 per cent. In the next τ_2, the attainment is to ½ of what was left over, or to ¾, and so on. This is an easy concept to remember or to explain. It is recommended that, in engineering, exponential time constants be replaced by binary time constants.

Decimal Time-Constant τ_{10}

Although from the practical and descriptive standpoints, the binary time constant τ_2 has marked advantages over the exponential time constant τ_ϵ, neither of these lends itself to ease of computation at indiscriminate values of t. We may however rewrite **(11)** in the form

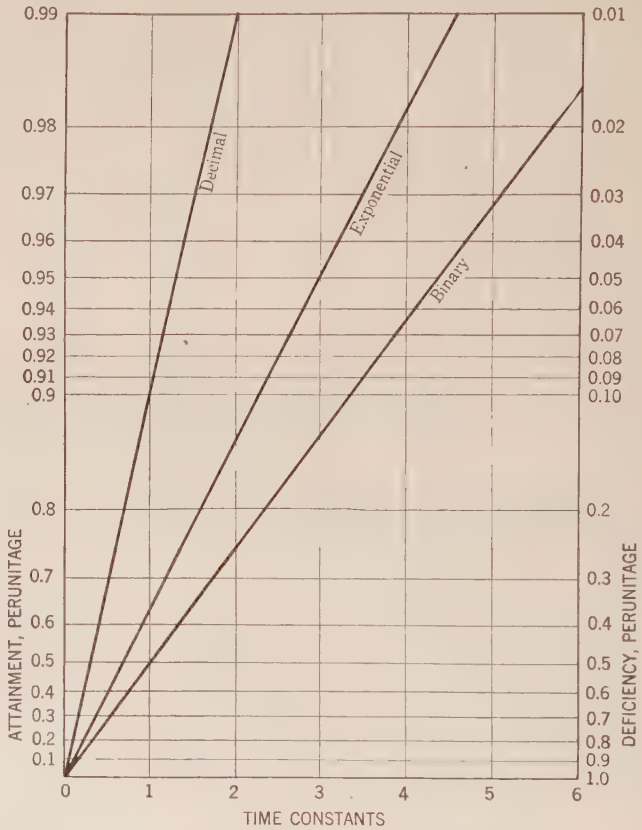

Fig. 5—Rectilinear Attainment-Time Constant Diagram on Inverted Arith-Log Paper, for Decimal, Exponential and Binary Time Constants

$$\frac{\delta}{\Delta} = \epsilon^{2.3026 \times -\frac{t}{2.3026\tau_\epsilon}} \quad \text{deficiency ratio} \quad (15)$$

$$= 10^{-\frac{t}{\tau_{10}}} \quad \text{deficiency ratio} \quad (16)$$

where

$$\tau_{10} = 2.3026\, \tau_\epsilon \quad (17)$$

By substituting the *decimal time constant* τ_{10} for the exponential time constant, we obtain in **(16)** an expression for the deficiency at any assigned value of t,

3. "Time Constants for Engineering Purposes in Simple Exponential Transient Phenomena" by A. E. Kennelly, *Proc. Nat. Acad. Sciences.* Nov. 1924.

4. "Practical Measurements in Radio-Activity." Makower and Geiger, 1912, p. 81.

which can be evaluated quickly with the aid of any ordinary table of logarithms.

In Fig. 3, the point g', where $t = 0.01151$, marks one decimal time constant. At this moment the current is at G, and the deficiency is 10^{-1}, or 0.1. The attainment is $(1 - 10^{-1})$ or 0.9. Again, at $t = 2\ \tau_{10}$, the current has reached L, where the deficiency is 10^{-2} or 0.01, and the attainment is $1 - 10^{-2}$, or 0.99. At $t = 3\ \tau_{10}$, the deficiency, at 0, is 10^{-3} or 0.001. From a practical standpoint, the decimal time constant is too long, since the attainment is then 0.9.

Fig. 4 shows the corresponding transient of decrease, when the switch S of Fig. 2 is closed. The curve in Fig. 4 is the same as in Fig. 3, but inverted. The same formulas apply and

$$i = 1.0 + 1.5\ \epsilon^{-\frac{t}{\tau_\epsilon}} \quad \text{amperes} \quad (18)$$

All three time constants τ_ϵ, τ_2 and τ_{10} are indicated in Fig. 4, and their applications are the same as in Fig. 3.

Straight-Line Graphs of Deficiency and Attainment on Inverted Arith-Log Paper

Fig. 5 shows that the graphs of attainment and deficiency become straight lines on inverted arith-log paper for all three time constants. Thus at one time constant, the attainment is 0.5 with the binary, 0.632 with the exponential, and 0.9 with the decimal time constant. With the aid of this chart, computations relating to simple exponential transients may be greatly simplified, for most engineering purposes. The temperature rise of any machine, under steady load and steady ambient temperature, will trace out a straight line with time as in Fig. 4, if the transient is strictly exponential and the final rise is known.

Time Constants Applied to Transient Temperatures of Dynamo Machines on Basis of Constant Losses During Transition

The following is a brief presentation of the well-known theory of transient temperatures in dynamos under steady load. It is assumed that the impressed speed is constant, in the case of a generator, impressed voltage in the case of a motor, impressed voltage and frequency in the case of a transformer. The machine is supposed to comprise a single thermal body, of perfect thermal conduction throughout. The machine starts at $t = 0$ hours, from an initial and constant ambient temperature T_a deg. cent., under continuous load, finally reaching a final temperature $T_m = T_a + \Theta_0$ deg. cent. The power losses in the machine remain constant at p_0 watts. The dissipation constant s of formula (2) is constant and also the thermal capacity k, in watthours absorbed per deg. cent. elevation of temperature. Then if θ is the instantaneous temperature of the machine at any time t, the heat generated in the machine during any short interval of time dt is $p_0\ dt$ watthours. During the same interval, the heat dissipated by the machine is $\theta\ s\ .\ dt$ watthours. If during the same, the temperature of the machine rises by $d\theta$ deg. cent. the heat absorbed in the machine will be $k\ .\ d\theta$ watthours. Equating the heat generated to the heat dissipated and absorbed,

$$p_0\ .\ dt = \theta\ s\ .\ dt + k\ .\ d\theta \quad \text{watthours} \quad (19)$$

Let

$$p_0 = \Theta_0\ s \quad \text{watts} \quad (20)$$

by (2). Then

$$(\Theta_0 - \theta)\ s\ .\ dt = k\ .\ d\theta \quad \text{watthours} \quad (21)$$

or

$$(\Theta_0 - \theta)\ .\ dt = \tau_\epsilon'\ .\ d\theta \quad \text{deg. cent hours} \quad (22)$$

where

$$\tau_\epsilon' = \frac{k}{s} \quad \text{hours} \quad (23)$$

τ_ϵ' is an exponential time constant. It may be called the *constant-loss time constant.*

Hence

$$\frac{d\theta}{\Theta_0 - \theta} = \frac{dt}{\tau_\epsilon'} \quad \text{numeric} \quad (24)$$

and

$$-\operatorname{logh}(\Theta_0 - \theta) = \frac{t}{\tau_\epsilon'} - c \quad \text{numeric} \quad (25)$$

where logh signifies the hyperbolic or Napierian logarithm, and c is an integration constant.

Then

$$\Theta_0 - \theta = C\ \epsilon^{-\frac{t}{\tau_\epsilon'}} \quad \text{deg. cent.} \quad (26)$$

When $t = 0$, $\theta = 0$ and $C = \Theta_0$.

Thus

$$\theta = \Theta_0 - \Theta_0\ \epsilon^{-\frac{t}{\tau_\epsilon'}} \quad \text{deg. cent. rise} \quad (27)$$

$$= \Theta_0 - \Theta_0\ 2^{-\frac{t}{\tau_2'}} \quad \text{" " "} \quad (28)$$

$$= \Theta_0 - \Theta_0\ 10^{-\frac{t}{\tau_{10}'}} \quad \text{" " "} \quad (29)$$

These results are in accordance with those obtained for the continuous-current transient of Figs. 2, 3 and 4, using the three time constants above referred to.

The instantaneous temperature elevation θ will be completely specified if we know the ultimate temperature rise Θ_0, and any one of the three time constants. The easiest time constant to measure is probably τ_ϵ, from a tangent to the curve of initial heating, assuming that the ultimate rise Θ_0 is known or is measured. We do not need to know either k or s. The attainment at any time is θ/Θ_0, and the deficiency $(\Theta_0 - \theta)/\Theta_0$.

Cooling Transient

The curve of cooling of a machine will be identical with that of heating inverted (see Figs. 3 and 4), if the dissipation constant s remains the same. In the case of an air-cooled transformer, this may be expected; but in the case of a generator or motor, this can only be expected if the speed of rotation remains the same during both cooling and heating. It is evident that s will be greatly diminished if the machine is stopped while cooling.

Time Constants Applied to Straight-Line Change of Losses During Transition

Fig. 6 represents an ideal diagram of losses in a machine operated at a steady output, commencing at an initial and ambient temperature T_a and terminating at a final temperature T_m deg. cent. $O\,P$ represents the internal losses p_0 watts converted into heat. Of this amount, a certain part, not definitely known, is in the copper windings, another part in the steel frames of rotor and stator, while the remainder will be in frictions of various kinds. If p_0 were constant throughout the transition, the loss would reach $A\,A'$ at the final temperature. Suppose, however, that the copper losses increase by an amount $A\,C$ along the straight line $O\,C$. This would be true if the current strengths in the windings remained constant, and the copper resistances increased with temperature in the regular way. Actually, the currents may have to be re-adjusted as the temperature increases; while the electric resistance of

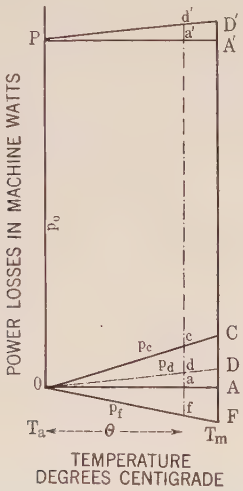

Fig. 6—Diagram of Assumed Straight Line Losses at Constant Output as Function of Temperature

carbon brushes, if used, may diminish. It will be sufficient that the actual change in copper losses does not depart markedly from a straight line $O\,C$. Again, the iron losses are likely to diminish as the temperature rises, because the resistance of the iron to eddy currents will increase; while the hysteresis losses remain substantially unchanged. We may assume that the change in iron loss will amount, at the maximum temperature, to a reduction $A\,F$ watts, and that it will follow a straight line $O\,F$. Actually, the change will be more complex; but it will suffice for most practical purposes if the deviation from the assumed straight line $O\,F$ is not serious. The total change of power losses over the transition will then be say $A\,D$, plus or minus, according to the predominance of $A\,C$ or $A\,F$. The total change with temperature will then also occur along a straight line $O\,D$, so that the total losses will follow the straight line $P\,D'$.

Let p be the power liberated in the machine at temperature elevation θ deg. cent. Then

$$p = p_0 + p_c - p_f \qquad \text{watts} \quad (30)$$

$$= p_0 + c\,\theta - f\,\theta = p_0 + d\,.\,\theta \qquad \text{"} \quad (31)$$

where c is the ratio $A\,C : O\,A$ or $\tan A\,O\,C$,
and f " " " $A\,F : O\,A$ " $\tan A\,O\,F$
" d " " " $A\,D : O\,A$ " $\tan A\,O\,D$

Then at any temperature elevation θ, the power liberated in the machine being $p_0 + d\,.\,\theta$, the heat liberated in time dt is

$$p\,.\,dt = (p_0 + d\,.\,\theta)\,dt \qquad \text{watthours} \quad (32)$$

The heat dissipated in the same time will be $\theta\,s\,.\,dt$ watthours; while the heat absorbed in the machine by a simultaneous small rise of temperature $d\theta$, is $k\,.\,d\theta$ watthours. Equating the gain and loss of heat, as in (19)

$$(p_0 + d\,.\,\theta)\,dt = \theta\,s\,.\,dt + k\,.\,d\theta \qquad \text{watthours} \quad (33)$$

Let $p_0 = \Theta_0\,s$, as before.

Then $\{\Theta_0\,s - \theta\,(s - d)\}\,dt = k\,.\,d\theta$ watthours (34)

or

$$\text{or} \quad \left\{ \Theta_0 \left(\frac{s}{s-d} \right) - \theta \right\} dt$$

$$= \left(\frac{k}{s-d} \right) d\theta \qquad \text{deg. cent. hours} \quad (35)$$

$$\text{or} \quad (\Theta - \theta)\,dt = \tau_\epsilon\,.\,d\theta \qquad \text{deg. cent. hours} \quad (36)$$

$$\text{where} \quad \Theta = \Theta_0 \left(\frac{s}{s-d} \right) \qquad \text{deg. cent.} \quad (37)$$

$$\text{and} \quad \tau_\epsilon = \frac{k}{s-d} = \tau_\epsilon' \left(\frac{s}{s-d} \right) \qquad \text{hours} \quad (38)$$

τ_ϵ may be called the straight-line variable-loss time constant, or simply the *variable-loss time constant.*

Equation (36) corresponds to (22), and its solution is

$$\theta = \Theta - \Theta\,\epsilon^{-\frac{t}{\tau_\epsilon}} \qquad \text{deg. cent. rise} \quad (39)$$

$$= \Theta - \Theta\,2^{-\frac{t}{\tau_2}} \qquad \text{deg. cent. rise} \quad (40)$$

$$= \Theta - \Theta\,10^{-\frac{t}{\tau_{10}}} \qquad \text{deg. cent. rise} \quad (41)$$

The effect of the variation of losses with temperature is to change both the ultimate rise and the time constant in the ratio $s/(s - d)$. If the losses are greater at the higher temperature d is positive; so that both Θ and τ are increased. The temperature elevation will remain a simple exponential transient, the curve of which will correspond to that of Fig. 3 for rises, and to that of Fig. 4 for falls. The exponential time constant of the curve, as obtainable from the tangent, will be τ_ϵ, and very nearly 70 per cent of this will be the binary time constant τ_2.

Cooling Curve with Normal Dissipation and Load Removed

If the load were cut off the machine and all excitation removed, while the normal dissipation was maintained

by continued rotation, the power liberated in the machine would be zero. Equation (33) then becomes

$$0 = \theta s \,.\, dt + k \,.\, d\theta \qquad \text{watthours} \quad (42)$$

$$0 = \theta \,.\, dt + \tau_\epsilon' \,.\, d\theta \qquad \text{deg. cent. hours} \quad (43)$$

$$-\ \theta \,.\, dt = \tau_\epsilon' \,.\, d\theta \qquad \text{deg. cent. hours} \quad (44)$$

$$-\ \frac{dt}{\tau_\epsilon'} = \frac{d\theta}{\theta} \qquad \text{numeric} \quad (45)$$

the solution of which is

$$-\ \frac{t}{\tau_\epsilon'} = \text{logh}\ \theta + c \qquad \text{numeric} \quad (46)$$

Hence $$\theta = \Theta\, \epsilon^{-\frac{t}{\tau_\epsilon'}} \qquad \text{deg. cent. rise} \quad (47)$$

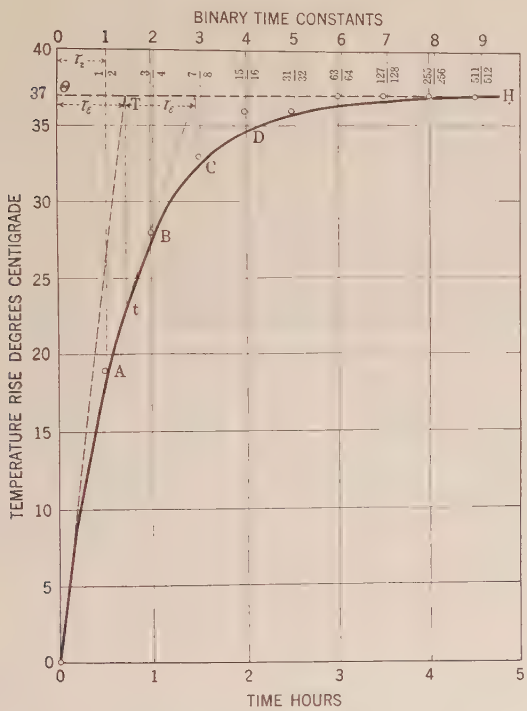

Fig. 7—Temperature Rise of Hottest Stator Lamina in Induction Motor

The time constant of this falling transient is not τ_ϵ but τ_ϵ'. Consequently, if the losses vary with the temperature at constant output, the curves of transient temperature will be simply exponential, whether with load applied or with load removed; but the time constants will differ. But since it is very unusual to run a machine steadily without load or excitation, the constant-loss time constant τ_ϵ' does not present itself in practise, and only the variable-loss time constant τ_ϵ comes into operation.

Although, under the above assumptions, the transient temperature of a dynamo machine in continuous operation from one steady load to another is a time-constant transient, yet it will be found on examination of such temperature curves that they deviate somewhat from strict time-constant curves, although for many practical purposes the deviations may be ignored. A principal cause for deviation is that the windings of a machine, with their copper losses, form one thermal system, and the steel structures, with their iron losses, form another. Each system has its own k, s and time constant. If the two systems were thermally independent, they could be measured apart; or, if the two systems were united by perfect thermal conduction, they would blend into one with a single time constant, as has been assumed above. But they are actually only semi-detached, being in mutual communication through thermal resistances; so that each tends to modify the behavior of the other, in a rather complicated way. The curves of transient temperature of the copper are affected by the influence of the associated steel structures, and reciprocally; so that neither can display a true time-constant curve.

By the courtesy of Mr. H. M. Hobart, a number of curves of transient temperature, in passing from one steady state to another, have been procured and examined for various types and sizes of machines. Two only of these are presented here, as examples.

Fig. 7 gives the observed hottest stator lamina temperature, as obtained by thermometer, on a particular 30-h. p. 3-phase, 6-pole induction motor, operated under steady load, at 500 rev. per min., from a 440-volt,

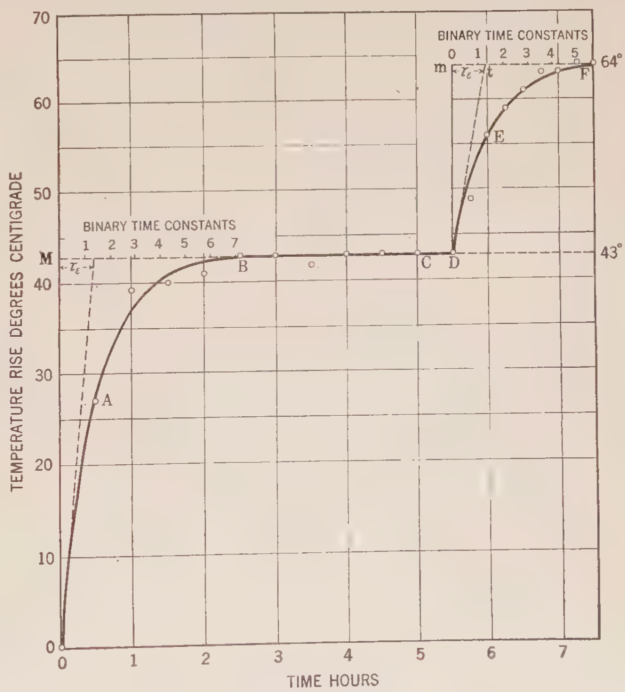

Fig. 8—Temperature Rise of Commutating Field Winding in d-c.-Motor

25 ~ circuit. The ambient temperature was 16 deg. cent. and remained within 1 deg. cent. of that value during the test. The small black circles, at half-hour intervals, indicate the observed temperature rise; while the curve $A\ B\ C - H$ shows a time constant computed on the basis of $\Theta = 37$ deg. cent. ultimate rise. The observations do not depart more than 1.5 deg. cent. from the computed curve at any point, but indicate a

tendency to exceed the curve near the middle of the run. Two exponential time-constants of about 44 minutes each are marked off on the 37 deg. rise line $T\,H$, by tangents from the curve. The binary constant τ_2 of about 30.5 min., is obtained by taking 70 per cent of τ_ϵ. Nine of these binary time constants are marked off. At the last, the rise should be theoretically within 1/512 of the final value.

Fig. 8 gives the corresponding data for a particular 4-pole, 50-h. p., d-c. motor, operating at 1075 rev. per min., on a 230-volt circuit. The motor was operated for five and one-quarter hours steadily, at rated load, and then after 15 min. intermission, at 125 per cent of rated load, for two hours more. The black circles give the observed temperature rise on the commutating field winding, by thermometer, above an ambient temperature of 15 deg. cent. at the beginning of the test. This ambient temperature rose steadily to 22 deg. cent. at the end of the run. The curve $O\,A\,B\,C$ is the computed time-constant curve, based upon an ultimate temperature rise of 43 deg. cent. The initial tangent $O\,T$ cuts this horizontal line at T, marking off an exponential time constant $M\,T = \tau_\epsilon$, of 30 min. The binary time constant was thus approximately 21 min. Seven binary time constants are marked off along $M\,B$, where the deficiency would be 1/128.

The overload-run temperature time-constant curve is $D\,E\,F$ based on a new ultimate rise Θ of 21 deg. cent. The initial tangent marks off an exponential time constant $m\,t = \tau_\epsilon$, of 30 min. as before, and five binary time constants are marked off along the ultimate-rise line $m\,F$. Half the ultimate rise should develop at 1, half the remainder at 2, and half the succeeding remainder at each successive binary time-constant interval.

It has recently been pointed out[5] that if after an interval of t_1 hours from a starting point on an exponential heating curve like that of Fig. 3, the temperature elevation reached is θ_1, while after an interval of $t_2 = 2\,t_1$ hours, it has reached θ_2, then the ultimate rise should be

$$\Theta = \frac{\theta_1}{2 - \theta_2/\theta_1} \qquad \text{deg. cent.} \quad \textbf{(47a)}$$

Correction for Change in Ambient Temperature During Run

If, as very frequently happens, the ambient temperature is observed to change during a run under steady load, some uncertainty develops as to the proper value to accept for the temperature rise Θ. The heat dissipated by the machine during the run tends to raise the ambient temperature. If the thermal time constant τ_2 were negligibly small, so that the temperature of the machine could follow impressed thermal forces without delay, the attained temperature elevation would always be equal to $T_m - T_a$; but there would be no need for carrying out a long continuous-load run, because such a machine would instantly reach its full temperature rise, on the application of the load. The longer the binary time constant, the greater the time needed for the machine to accommodate itself to a change in ambient temperature. Some correction of the observed temperature rise is therefore necessary for changes in ambient temperature. Such corrections should not require much computation, and should be easily applied; because with ordinary care, neither the change in ambient temperature nor the correction for it need be large.

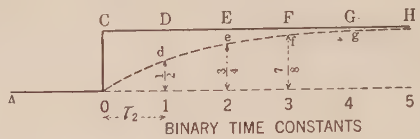

Fig. 9

In Fig. 9, the ambient temperature T_a, after pursuing the uniform stationary line $A\,B$, is supposed suddenly to rise by an amount Δ deg. cent. to C, and thereafter to continue unchanged with time, along the straight line $C\,D\,E\,F\,G\,H$. Commencing at O, the moment of change, binary time constants τ_2 are marked off along the time axis 1 2 3 4 5. After say three time constants have elapsed, the machine will theoretically have acquired at f, a thermal state corresponding to 7/8ths of the full change Δ, and no correction from the ambient temperature $T_a' = T_a + \Delta$ will ordinarily be required

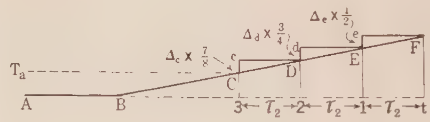

Fig. 10

if Δ is small. The temperature elevation at any time after F will thus be

$$\theta = T_m - T_a' \qquad \text{deg. cent. rise} \quad \textbf{(48)}$$

where T_m is the observed temperature of the machine. But immediately after the instant C Fig. 9, the ambient temperature should be reckoned as T_a and not T_a'; because the machine has not had time to respond. At D, after one time constant, the corrected value of T_a' would be $T_a + \Delta/2$. At E, it would be $T_a + 3\Delta/4$.

The conditions relating to Fig. 9 suggest the following simple approximate correction to be applied when the ambient temperature is changing. Suppose that the observed ambient temperature follows the lines $A\,B\,C\,D\,E\,F$ in Fig. 10, and that at the instant t, when the ambient is at F, and the temperature at some warm part of the machine under observation is then T_{mf}. Required the corrected ambient temperature T_{af}, so that the corrected temperature rise may be taken as

$$\theta_f = T_{mf} - T_{af} \qquad \text{deg. cent. rise} \quad \textbf{(49)}$$

5. "The Temperature Rise of Electrical Machinery" by T. R. Rowlands, *The Electrical Review*, London, correspondence 4th July 1924, page 11.

Find the variable-loss binary time constant τ_2 of the machine, as previously described. Measure off three of these time constants along the time axis, as at C, Fig. 10. Between C and D, the change was gradual; but assume that it occurred suddenly as $C\,c$. The corresponding sudden changes at D and E would have

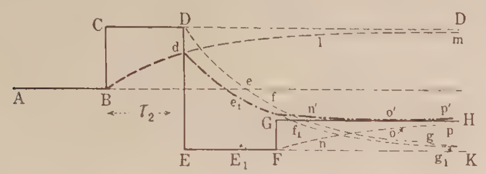

FIG. 11

been $D\,d$ and $E\,e$ deg. cent., respectively. Let the three disturbances be denoted as Δ_c, Δ_d and Δ_e, the signs of which are all the same in the case considered. Then

$$T_{af} = T_{ac} + \frac{7}{8}\Delta_c + \frac{3}{4}\Delta_d + \frac{1}{2}\Delta_e \text{ deg. cent.} \quad (50)$$

In the case considered, with uniform ambient rise from C to F, the uncorrected ambient temperature would be $T_{ac} + 3\,\Delta_c$. The approximately corrected value would be, by (50), $T_{ac} + 2\frac{1}{8}\,\Delta_c$.

In this approximate correction process, it is assumed that a change in ambient temperature which occurred 3 or more time constants back, has produced its full effect on the temperature of the machine.

Effects of Oppositely Directed Changes in Ambient Temperature

If the ambient temperature pursues in time the course $A\,B\,C\,D\,E\,F\,G\,H$, Fig. 11, changing its value suddenly at B, D and F, the effects successively produced in the inferred ambient temperature of the machine may be obtained by superposition. If the ambient temperature, after changing abruptly from B to C, were to continue unchanged thereafter, it would follow the horizontal straight line $C\,D\,D'$, parallel to the time axis. The effective ambient temperature of the machine, with a binary time constant τ_2, would follow the time-constant curve $B\,d\,l\,m$, ultimately coinciding with $D\,D'$. Again, if the abrupt change from D to E in the minus direction, were followed by a stationary condition, the ambient temperature would pursue the straight line $E\,F\,K$. The effect of this negative change $D\,E$, acting alone, would be to produce the time-constant curve $D\,e\,f\,g$. The negative ordinates of this curve are now applied to the curve $d\,l\,m$, to produce the resultant curve $d\,e, f, g$. The third positive change $F\,G$, acting alone, would produce the time-constant curve $F\,n\,o\,p$. The positive ordinates of this curve, with respect to $F\,K$, are now applied to the previous resultant curve e, f, g, producing the final resultant $G\,n'\,o'\,p'$. The course of the effective ambient temperature is thus $B\,d\,e$, $G\,n'\,o'\,p'$, which happens to end close to the final actual ambient temperature H.

Approximate Correction of Ambient Temperature When Varying Oppositely

Applying the above principles to the general case of a slowly wandering ambient temperature, the changes of which are kept relatively small, but have varying directions, we proceed as in Fig. 12; the method is the same as in Fig. 10, but the application is more general. Let $A\,B\,C\,D\,E\,F\,G\,H$ be the observed course of the ambient temperature with time. At the time t_H, corresponding to point H, it is required to find the approximate effective ambient temperature. Measure back three binary time constants along the curve, marking them off at G, E and C. It is assumed that T_{ac} the value at C, is the ambient temperature for correction. The changes in ambient $C\,c$, $E\,e$ and $G\,g$, occurring in each of the three time constants, are drawn. The hypothetical path of the ambient temperature is then $C\,c\,E\,e\,G\,g\,H$. It is assumed that the effects of these three sudden changes will be substantially the same as those of the wandering changes $C\,D\,F\,H$. Let the three hypothetical displacements be denoted by Δ_c, Δ_e and Δ_g, respectively. The first two have the $-$ sign and the last one the $+$ sign. Then

$$T_h = T_{ac} + \frac{7}{8}\Delta_c + \frac{3}{4}\Delta_e + \frac{1}{2}\Delta_g \text{ deg. cent.} \quad (51)$$

the proper signs of the Δ terms must be carefully followed.

In particular cases, a more elaborate correction formula may be called for. In such a case, the cor-

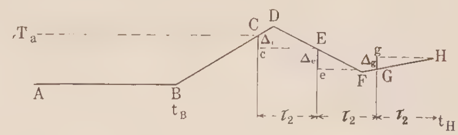

FIG. 12

rection might be carried back to cover four binary time constants instead of three, and each time constant might be divided into two equal parts. There would then be eight perpendiculars of the type $C\,c$, $E\,e$ and $G\,g$, Fig. 12. Calling them $\Delta_a, \Delta_b \ldots . \Delta_g, \Delta_h$, the factors to apply, with the proper sign in each case, may be taken as

$$\frac{15}{16}\Delta_a + \frac{9}{10}\Delta_b + \frac{7}{8}\Delta_c + \frac{4}{5}\Delta_d + \frac{3}{4}\Delta_e + \frac{13}{20}\Delta_f$$

$$+ \frac{1}{2}\Delta_g + \frac{3}{10}\Delta_h$$

Power-Factor Correction

By L. W. W. MORROW*

Member A.I.E.E.

Review of the Subject. — *Power factor correction has become a commercial problem of major importance, and technical knowledge and corrective equipment are available to make correction a part of the activities of the electrical industry. Field studies on several properties show power factor correction can be obtained without difficulty.*

Conditions can be improved by requiring all new business to be installed for high power factor operation and a coöperative movement should be made to bring about this condition. The situation on existing systems can be improved in either a wholesale or retail manner depending upon conditions.

Cost analyses should be made to determine the type of correction to use and to decide upon the location of corrective equipment. But they should not be used for rate making purposes. A study of the types of systems in existence shows that in general correction is most economically and most effectively instituted at the loads. Also experience indicates the greatest effect of correction is to improve voltage regulation and service quality.

Different types of rates and billing methods have been used, but a study of the art shows the kv-a. demand charge and the kw. energy charge can be used most successfully to secure power factor correction.

THE effects of low power factor on the operations of the electrical industry have been discussed for many years and much experience in the institution of corrective measures has been had. Yet on an industry-wide scale the evils associated with low-power-factor conditions become greater each year, even though the incentives for the institution of corrective measures increase. Low power factor has come to be recognized as the major handicap to better and more efficient electric service, and men of the industry are striving actively for a commercial and engineering method for its correction.

An analysis of the data and experiences of those properties which have instituted power-factor correction leads to the conclusion that operation under high-power-factor conditions improves both the quality and the efficiency of the service rendered by the utilities and used by their customers. Correction of power factor has its greatest influence in improving the voltage regulation and through this action enables the utility to give better service and the customers to secure better use of the service. Secondary gains resulting from power-factor correction consist of the release of system capacity with a consequent reduction in investment and a reduction in system losses with a resultant reduction in operating charges. Thus correction tunes the system and makes it cheaper and easier to give service of the quality desired in modern industry.

Actual experience shows that power-factor correction can be instituted successfully as a part of the business activities of light and power companies and as a part of the normal operating activities of industrial users of electricity. It does not require an elaborate or costly departure from customary business activities, and it secures returns to the producer and the user whose value is tangible and worth while. Yet little actual progress in power-factor correction can be seen because of many obstacles, mostly imaginary, set up in the minds of executives, engineers and customers. Some of these are: the inertia encountered when proposing any changes in a going business which is prosperous and follows time-tried methods; difficulties met in attempting to evaluate the costs of either low or high power-factor operation; fears introduced by the necessity for instituting new or changed rates and billing methods; difficulties encountered in attempts to make people understand the meaning of power factor; obstacles encountered in attempts to devise a correction scheme for universal application, and technical difficulties met with in connection with the selection and location of corrective equipment. The literature of the industry is filled with objections to power-factor corrective measures and with elaborate technical and cost analysis, and very few data or opinions of a constructive character have been obtained to show that most of the obstacles to correction result from misconceptions and lack of actual experience with it in commercial practice.

The fact is that many properties have instituted correction successfully and made it a profitable part of their business. They have done this without any difficulty and did not find any great complexity or major changes introduced in their operating routine. Thus the time is ripe and the methods are available for eliminating low-power-factor conditions in the electrical industry. The rewards are ample, and the necessity for this move becomes greater with the growth of electrical systems.

Correction is a business problem and not a technical problem. The technical features of power-factor discussions begin nowhere and end at the same place, and they have little if anything to do with the business-like application of corrective measures. No one can define electricity or power factor, yet definite laws enable engineers to use

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resistance, inductance and capacity in circuits or in machines to secure any desired power factor at any definite place. Also, engineers understand fully the influence of lagging and leading current on system regulation and machine stability. Technical mastery of power factor prevails, and what is needed is commercial mastery.

In order to obtain commercial mastery two suggestions are offered which will apply to every electrical system:

1. Require high-power-factor operation of all new business served.

2. Correct low-power-factor conditions on existing systems either: (a) promptly and in a wholesale manner, or (b) slowly and by steps.

Make New Business Good Business

Any consideration of the first suggestion, in the light of the growth of the electrical industry and the increasing importance of service quality, shows its logic, and there remains then the use of definite methods to secure the desired results.

A light and power company is a public utility and cannot enforce any rule requiring customers to install high-power-factor equipment before it will give service, so this direct and self-evident method must be replaced by methods which are co-operative and educational in character. The job requires the co-operation of utility men, electrical manufacturers and customers and must be done for each new business prospect on each property, and in addition work must be done on a national basis. It is not a difficult task, for both means and methods are available for doing the work quickly and efficiently.

The co-operative element in the work calls for:

1. Closer contact between central-station power salesmen and prospective customers whereby guidance and expert knowledge are made available to customers.

2. Closer contact between central-station executives and electrical manufacturers so the manufacturers may be encouraged to build high-power-factor equipment and to sell this equipment on a quality rather than a price basis and with greater consideration for the engineering requirements of the purchaser.

These two co-operative suggestions are already in operation in large degree, but conscious executive attention should be given to their application in order to secure complete commercial results rapidly. The job requires that each new customer install available electrical equipment from the standpoint of his own economic production requirements. Both power factor and quality apparatus will inevitably follow every real economic analysis of an industrial electrical application, and central-station men and manufacturers' representatives must give up the slogan that any new business is good business and do more to help their customers secure quality service and co-operate more closely to sell quality equipment. It would seem easy to organize a local co-operative committee for each utility to secure the desired results. This would be composed of power salesmen, electrical manufacturers' representatives, electrical contractors, and perhaps consulting engineers, and might well be part of the activities of the local electrical leagues already instituted in so many cities. National agencies are already available in the N. E. L. A., Power Club and other associations, but their attention must be given to this problem.

There is no handicap to the manufacture and sale of electrical equipment and service on a quality rather than a price basis in an industry whose product is popular, is necessary to industry and is the cheapest and best element ever introduced into industrial processes. When the cost of power is such a small fraction of the cost of manufacture of most industrial products, it is false economy to talk first cost of service or of equipment to purchasers.

Thus very little organized effort should institute as industry-wide practice the custom of obtaining only high-power-factor business in each new load added to existing systems. The principle to apply is that service to customers should be given before they install equipment and ask for electrical energy from a utility.

The Correction of Existing Conditions

The second suggestion for power-factor correction is that existing conditions be bettered either by making corrections quickly on a wholesale basis or by improving conditions slowly and in steps. In many respects the slow and detailed method is best for those systems inexperienced in correction, but past experiences show that it is not difficult to do the whole job quickly on the entire system provided proper analyses are made and workable methods are adopted before correction is actually instituted. Whatever decision is made has little influence upon the methods used or the results obtained and predominantly influences only the time required to secure improvements in conditions. The situation on each system will determine the best procedure to use, for operating and financial requirements must be met by individual properties.

Three things only are needed to institute correction on an existing system:

1. Decisions as to the location of corrective equipment.

2. Decisions as to the corrective equipment to be used.

3. The establishment of a rate system which takes power factor directly or indirectly into account.

The first two requirements largely involve engi-

neering and economic data and decisions to be secured within a utility organization, but the third requirement must take into consideration the utility, the customers and the regulatory commissions and involves public relations, economics and education.

Locations for Corrective Equipment

A study to determine the locations in which to install corrective equipment on existing systems shows that the decision is somewhat influenced by the type of system and by local conditions. Usually corrective equipment should be located at all low-power-factor loads, in some cases at substations at a distance from generating stations, particularly if voltage regulation is desirable, and in very few instances in generating stations. The source of low power factor is at the load, and analyses will show that corrective equipment is best and most economically used in this location.

Some of the types of systems encountered in this country and some of the elements faced in locating corrective equipment are enumerated below:

1. A hydroelectric system containing long high-voltage transmission lines with one or more distribution systems located at the ends of the lines.
2. A combination system having both steam and hydro stations, many high-tension lines and widely distributed load centers.
3. A hydroelectric system with standby steam stations containing capacity idle a great part of the time and made up of networks of high-tension lines supplying a scattered territory.
4. A metropolitan system containing several large steam stations and made up of both overhead and underground transmission circuits.
5. A system already operating and designed for a power factor of 80 to 85 per cent.
6. A system designed to operate at a power factor of 90 to 95 per cent.
7. Systems which are growing rapidly in magnitude of load and extent of territory covered and those which have reserve capacity through interconnections.

It is seen that each system is a specific study for power-factor correction at other places than at the load sources of low power factor, and the choice of location of corrective equipment at other locations must be made after economic and operating studies. The making of cost evaluations for a particular system should be decided upon only after careful study, for they are difficult and are useful only in serving as guides for the location of corrective equipment. They serve no purpose in rate making as cost-of-service rates are now obsolete in the utility industry. However, if cost analyses are desired in some cases, the usual approach to determining fixed and operating charges is to evaluate the cost of capacity and of losses in generating stations, transmission lines, substations, transformers and distribution systems.

Generating Station Correction

The evaluation of the reduction of the reactive-kv-a. load on a generating station due to power-factor correction is difficult because so many conditions must be considered. There is much more to the problem than raising a station power factor from 70 per cent to 90 per cent in order to make available approximately 20 per cent increase in station capacity.

In hydroelectric plants if is usually desirable to have reactive kv-a. available for line regulation, and in addition it is usual to find an excess of capacity installed in order to meet stream-flow conditions. Therefore, generally, no value can be placed on power-factor correction for such stations. Also, in large systems using steam and hydro stations in combination with interconnected high-tension lines, lagging current is often an operating asset, and in this case also correction is seldom or ever desirable for generating stations.

In the large steam stations feeding a power system concentrated in a comparatively small area power-factor correction may improve regulation and operation, but here again the savings in station costs are sometimes very small and must be evaluated for the conditions encountered. These plants are usually designed for 85 to 90 per cent power-factor operation at the stations, and a little study will show that cost decreases are difficult to secure. Offhand it may be said that every kv-a. of station capacity means the release of fixed charges on at least $6 of investment and every reduction of a per cent in losses from the normal 2 per cent of output kw.-hr. can be credited in dollars and cents of operating charge. But there are some other factors that must be considered before these sums mean anything or will stand the examination of a court or commission; for example, in connection with stations in modern systems:

(a) Most systems increase their installed station capacity in units of large size and seldom permit their peak to approach a value equal to installed capacity. For example, station additions are made in units of 30,000 kw. up to 200,000 kw. and ample reserve is held at all times.

(b) Every metropolitan system often introduces large losses into its normal operations in order to insure reliability of service; for example:

(1) A station having several large units is likely to continue all of them in operation even at very light load in order to reduce the starting hazard and the time element involved in warming up a large unit and synchronizing it with the system.

(2) In order to control voltage and load division

it is common practice on systems having multiple stations to operate generating units with large lagging or leading currents.

(c) It is a difficult, if not impossible, task to determine actual station power-factor conditions during a twenty-four-hour period for the different stations in a large metropolitan network. Any method of determining power factor and of determining the value of losses is subject to criticism as to its technical accuracy, and the values obtained cannot be divided easily between power factor, load division and regulation requirements. In fact, for a given load power factor as defined and as measured by different methods will vary 10 to 30 per cent in value.

The actual capacity cost of the reactive load on a generating station not loaded to capacity is usually very little even though the cost of the increased capacity of alternators, exciters, switch gear, buses and building is determined. Seldom would this cost exceed $6 per reactive kv-a., and any added operating expense due to low power factor is very debatable. For some specific installations, however, where the peak load is equal to the station capacity or where the load power factor is lower than that for which the station equipment was designed, it may be well to institute power-factor correction as a temporary economical expedient for securing capacity to carry the load. Load factors, future system growth and other elements, however, must be considered.

In most other cases, however, it is cheaper and easier to buy, install and operate alternators, buses and exciters with a higher rating than it is to buy, install and operate corrective equipment and its control. For example, the increment cost of a 35,000-kv-a. alternator over a 30,000-kv-a. unit as compared to the cost of a 5,000-kv-a. synchronous condenser and its control equipment is in favor of the alternator. In most stations generating capacity can usually be obtained more cheaply than by the use of corrective equipment.

Very few operating costs are affected by low power factor because the copper losses inside a station amount to an inappreciable sum. At light load the usually lowest power-factor condition increases the losses in proportion to the kw. output. This indicates the advisability of fixing a power-factor charge that varies with output. This charge should be greatest at minimum-load conditions in some cases and at peak-load conditions in other cases. A very small increment in energy charges seems the only businesslike way to cover these station losses due to low power factor as at a maximum they comprise only 2 or 3 per cent of the system losses.

The practical possibility and the dollar value of regulation by power-factor correction inside large steam stations is very dubious. The unit type of installation with the unit bus and a group of feeders for each unit has become popular, and it is difficult to conceive of this type of station operating with all buses in parallel at one voltage or to devise a switching and bus arrangement for throwing the synchronous condenser on any feeder requiring regulation. In addition, the cost of the corrective equipment used for regulation exceeds that of voltage regulators, which have the added advantages of being automatic in their operation and of having a greater voltage range.

In the general case, therefore, seldom will it be found economical to institute power-factor correction in generating stations.

SUBSTATION CORRECTION

The installation of corrective equipment at substations reduces the kv-a. load on transmission lines and transformers between the substations and the generating stations and improves the voltage regulation. This would seem desirable in all cases, but a little study shows it is often very uneconomical and usually not the best way to secure complete correction.

In modern systems reliability of service, provision for future growth and maintenance practices dictate the use of multiple feeders to substations and multiple transformer installations. Also, modern practice tends to the use of standardized ratings for lines and transformers on the transmission system. These requirements call for the installation of a greater number and an excess of line and transformer capacity, which makes it very difficult to show the economic value of substation corrective equipment.

Moreover, it must be borne in mind that future load requirements, structural needs and legal limitations have a direct bearing on both overhead and underground line installations. The overhead line must have a certain size of pole, a conductor sufficiently large to be strong mechanically, a large number of poles per mile and very often a legal voltage limitation. These elements often must be weighed carefully when discussing the release of line capacity by the use of substation corrective equipment. In underground cable installations it has become customary to install reserve ducts and cables and to standardize greatly, so the number and the capacity of installed cables at a given time is very often determined by other things than the magnitude of the kv-a. loads. It must be considered, however, that the overload capacity of an overhead line is very great as compared with that of cables and transformers.

Thus any cable or transformer that has reached its limit in capacity while operating at a low power factor is capable of carrying an increased load and consequently earning more revenue if correction is applied at substations. The cost of the corrective

equipment may be less than the installation of another line and more transformers, and regulation is improved, so that more load may be carried on a given circuit. In other words, correction will, for the same line loss, increase either the economic distance of transmission or the amount of load possible to transmit. In such cases the substation correction may be economical, but it is an expense which must be paid for in fixed charges, while a new line provides a revenue-producing and useful element for the present and future system. A system using a ring high-tension network and having multiple generating stations and several large substations on the ring may use corrective equipment in distant substations to advantage to reduce losses, release capacity and control regulation, but the economic value of this practice must be ascertained for each particular case.

Thus in very few cases will the release of system capacity justify substation correction; therefore either decreased losses or improved regulation must be evaluated to make a case. The reduction in line and transformer losses by the use of corrective equipment increases the load at which the investment cost per kv-a. transmitted is a minimum and reduces the direct operating cost of energy losses. On an average system the line energy losses will be around 10 per cent of the total output while the transformer losses should not exceed 5 per cent. These losses therefore represent a direct money loss, which, if reduced, results in an appreciable saving. Assuming that correction decreases these losses even 20 per cent, it often becomes profitable to install corrective equipment.

For example: Assume an energy cost of 1 cent per kw.-hr. and a system output of 100,000,000 kw.-hr. with total losses of 15 per cent in lines and transformers. If it is assumed correction will reduce the losses 20 per cent, the yearly value of correction is: 100,000,000 x 0.15 x 0.20 x 0.01 = $30,000, or a return of 15 per cent on an investment of $200,000.

Losses in corrective equipment must be considered in a financial analysis of this character and their cost determined. If synchronous condensers should be used, this value would be changed, since the condenser has losses which must be charged against the saving produced in lines and transformers. If static condensers are used, the value of the losses in the corrective equipment is very small. In either case, particularly if the voltage at the substation is high, the losses in the transformer bank supplying the corrective equipment should be evaluated and charged against the cost of correction.

The general conclusion is that substation correction, considering the value of losses, capacity and regulation, is usually warranted for those substations located at a distance from generating stations, at least as a temporary move, until full consumer correction has been established.

Consumer Correction

The analysis for determining the proper location of corrective equipment leads inevitably to the conclusion that most of it should be placed on the premises of consumers and that consumers using high-power-factor equipment are operating most economically from their own standpoint and from that of the central station. From the angle of the central-station consumer correction relieves the system of the necessity for correction at other locations, releases the transformer and cable capacity where it is most valuable from income and load-factor standpoints, reduces losses where they are greatest and improves regulation where it is most desirable to have good regulation.

From the angle of the consumer correction of his equipment or the replacement of low-power-factor equipment with high-power-factor equipment will secure several tangible and intangible results. It will reduce the losses inside his premises, for which he pays a high rate; it will improve his voltage regulation and reduce his voltage drop, so that his machinery will operate faster and more smoothly; it will give him better-quality production, better lighting, fewer rejections of manufactured product, faster machine-starting conditions and secure for him a direct decrease in his power bill if he buys under a proper rate system.

Experience shows that operating complexity is not increased and that the industrial plant corrected for bad power-factor conditions reaps very decided tangible and intangible benefits. Needless to say, it is useless to attempt an itemized cost evaluation for correction at load locations, because the complexity of modern distribution systems, the variety of loads and services and the many assumptions necessarily made all combine to give inaccurate results. In a broad way, however, based on the actual cost of the distribution system, the cost of voltage regulation and the cost of losses, an analysis in dollars will show very decided inducements for investing power-factor correction at the source.

Kinds of Corrective Equipment

The corrective equipment to install at locations decided upon is determined largely by each local situation, but there are applications for all available types at low-power-factor loads; i. e.:

(a) The synchronous motor.

(b) The synchronous condenser.

(c) The high-power-factor commutating motor of the Fynn-Weichsel type.

(d) The static condenser.

Investment charges on existing installations, production requirements, fixed and operating

charges on corrective equipment and the skill required to operate the equipment influence the decision to be made for each load considered.

For substation correction the same types of corrective equipment are available, but the synchronous condenser and group static condensers predominate. The decision as to which type to use at substations is influenced by cost analyses and by load and voltage regulation requirements.

Experiences on properties give evidence that the choice of equipment for correction is quite readily made for a particular location. Each system should be studied as a whole and each power customer considered if good results are desired. The utility engineers can readily determine the substation correction to use, but greater difficulty is encountered in the correction of power customers. The installation of each customer must be studied in detail if a real engineering job is to be done, and this requires time, skilled engineering and an expenditure of money. Production processes, motorization, wiring and testing are elements in the study, and a great deal of education and co-operation must be had. For these reasons a slow process of customer correction is usually advisable. Utility power salesmen, consulting engineers, factory engineers and electrical manufacturers' salesmen and engineers should co-operate in these customer studies. In actual practice no great difficulty or high costs have been encountered in attempts to institute customer corrections, because the great majority of them can be made adequately by an over-all factory test or by competent engineering inspection. Very frequently zone studies or piecemeal areas are corrected with very little trouble.

Power-Factor Rates

Electric service is a business and as such must institute power-factor correction as a part of business activity. Thus a rate of some form must be used to secure power-factor correction, and it also follows that metering and billing accompany the institution of a rate. Experience with energy and power-factor rates over many years shows that commercial rates cannot be made upon the basis of cost of service. Experience also shows that financial inducements are the best stimuli to industrial accomplishments. Rates, billing systems and metering methods are largely matters of tradition and commercial application, but should be simple, understandable and easy to use in business.

When alternating current was first used the wonderful Thomson-Houston meter was invented and installed. This meter measured watt-hours and eliminated the necessity of measuring ampere-hours and multiplying by the normal voltage of the service as had hitherto been practiced. It was an ideal instrument for measuring lighting loads, and no thought was taken on its ultimate effects on the utility business. Rates were made on a watt-hour basis and the cheap, accurate watt-hour meter became the standard measuring device for electric service. Then came the induction motor and it was early noticed that the product of current and voltage did not equal the registration of the meter. Thus power factor was discovered, and until recently the utilities decided that it was better to suffer its effects than to attempt to improve conditions or to charge for service by methods involving the use of other units than watt-hours. Power factor was difficult to define accurately, difficult to measure and still more difficult to explain to customers and executives.

However, there is a tendency today actually to measure power factor or to meter customers by methods which will take power factor into account. The first trend is indicated by the development of kv-a. meters, the use of reactive and active watt-hour meters and the use of power-factor meters. Any of these meters or metering methods are subject to objections from an economic, a technical and an operating standpoint. The cost, the complexity of the billing and the difficulty of obtaining and maintaining reliable and accurate measurements by any of these means have so far prohibited their use except for large power customers having a technical staff or sufficient consumption to warrant the cost and the trouble. Nothing very promising is on the horizon in the way of directly measuring either kv-a. or power factor on a universal commercial basis.

One metering authority has recently suggested that it would be advisable to meter customers on the old ampere-hour basis since all service is at practically constant voltage and the ampere-hour meter, besides being cheap and accurate, is a true and readily understood measure of both energy and capacity use. Multiplying ampere-hours by the voltage of the supply would permit of billing on a kv-a.-hour basis very readily. Thus a system could be developed which would use an ampere demand meter and an ampere-hour meter only for direct measurement on any three-phase or single-phase circuit. It is argued that this method is sufficiently accurate, is easy to institute, is logical and that its results compare well in accuracy with those from any existing method of measurement.

The ultimate approach to power-factor correction for customers is by means of rate making. This has generally taken the form of:

(a) The use of power-factor clauses.
(b) The use of kv-a. demand clauses.
(c) The use of kv-a.-hour clauses.
(d) A combination of two of the foregoing.

All these methods have been used and all have worked more or less successfully, but all are sub-

ject to very definite criticisms. Years of effort proved the impossibility of developing utility rates on a cost-of-service basis, and, however reluctantly, rate makers have admitted its impossibility and impracticability for modern conditions of utility service. No cost-of-service basis can be found, therefore, for the making of any type of power-factor rate, and each property must evolve a rate which can be instituted and operated to suit conditions encountered. A fundamental in power-factor rate making would be to secure a simple rate, one that could be applied to all customers, one that needed little maintenance or supervision and one that offered a financial inducement to customers to maintain and correct power-factor conditions.

Viewing the art in its technical and commercial aspects and basing opinions on practical experiences, the best form of power rate today should use a kv-a. demand charge to cover capacity costs and an energy charge to cover production costs. Power factor, as such, should not appear in the customer rates, but should be accounted for in the kv-a. demand charge. This rate can be used to secure power-factor correction on any system very satisfactorily and does not necessarily involve the use of a kv-a. demand meter. Power customers can be tested under normal operating conditions, and the power contract can then be written for a period of time with a kw.-hr. meter and a kw. demand meter to serve as checks and for energy billing. In other cases the installation of a power-factor meter, normally out of circuit, in combination with ordinary watt-hour meters can be used to check customer conditions and to meet billing requirements.

However, every type of power-factor rate has been used and used successfully, so the necessity of a rate to secure power-factor correction is not a real obstacle to the institution of correction. It must be remembered that grand average results only are to be expected and that precision methods and analyses must be modified by commercial considerations.

Testing High-Tension Impregnated-Paper-Insulated, Lead-Covered Cable

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Synopsis.—*The increase in voltage of cables has necessitated that the tests to assure satisfactory cable be more adequate than as standardized at present. This has resulted in an intensive study of the tests previously standardized, development of new tests, and the design and manufacture of suitable testing equipment to meet the new testing requirements.*

Measurements are made upon cables to determine the following properties of the insulation:

Insulation Resistance
Dielectric Strength
Dielectric Power Loss and Power Factor
Capacitance
Ability to Withstand Bending

Insulation Resistance: This measurement is being made in the same way on cables of all voltage rating. The results of the test on high-tension cables are of doubtful value as a criterion of the suitability of cable for use. Continued study of this measurement should be made.

Dielectric Strength: Suitable testing equipment for satisfying the requirements of the increased voltages in dielectric strength tests has been made available. This includes sine-wave generators, adequate testing transformers, appropriate cable testing terminals.

Data is given from which conclusions are drawn as to the magnitude and duration of test voltages. The adequacy of these values will become known through experience. The need for field testing is shown.

Dielectric Power Loss and Power Factor: The tendency is to extend the measurement of dielectric power factor to include each reel length to be shipped. The Schering Bridge for making such measurements is described. The need for standardizing the testing procedure for power factor measurements is shown.

Testing Installed Cable: The study of so-called "current-time curves" for rating installed cable should be continued. Preliminary measurements made at high frequencies as a means of rating installed cable did not show the results to be immediately usable.

Testing With Direct Current: Data is given to show the d-c. to a-c.-ratio of breakdown voltage of some samples of 12 kv.-3-conductor. cable. Tests indicate that the d-c.-to a-c.-ratio will depend upon many conditions such as nature and structure of the material, thickness of the material, temperature of the material, shape and size of electrodes, and rate of application of the applied potential.

THE report of the Transmission and Distribution Committee of the A. I. E. E. for 1923-1924 contains the following significant statement:[1]

"The most important development during the past year has been the evidence that the cable specifications of the N. E. L. A. and the present Standards of the A. I. E. E. do not insure satisfactory cable for the higher operating voltages.

"This subject is now receiving attention from the manufacturers as well as the users of high voltage cable and as a result of these studies, it is hoped that it will be possible:

First to make the necessary changes in manufacturing

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1. For References see Bibliography.

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processes and materials so as to secure a satisfactory cable for operation at the higher voltages, and

Second to devise a method of testing high voltage cable which will determine its operating characteristics in advance of its installation."

The present paper discusses some phases of the second of these two objectives, not that such a method for which engineers are eagerly searching has been finally devised, but because a discussion of the conditions under which the present tests are applied may be helpful in so modifying them that they may be made more adequate.

The tests at present standardized for determining the suitability of cable for use as regards the insulation are as follows:

I. *A. I. E. E. Standards 1922*:
- A. Tests to be made on each length to be shipped.
  1. High-voltage test
  2. Measurement of insulation resistance
  3. Measurement of capacitance
- B. Test to be made on samples (10 ft. of lead)
  1. Measurement of ultimate dielectric strength

II. *N. E. L. A. Specifications for Impregnated Paper-Insulated, Lead-Covered Underground Cable, 1922*
- A. Tests to be made on each length to be shipped
  1. High-voltage test
  2. Measurement of insulation resistance
- B. Test to be made on one reel length per 15,000 ft. of cable
  1. Measurement of dielectric power loss and power factor at about 85 deg. cent.
- C. Test to be made after installation when cable is installed by the manufacturer
  1. High-voltage test
- D. Tests to be made on samples
  1. Measurement of dielectric strength
  2. Bending test
     - a. Wrinkling of lead; dielectric strength; visual examination
     - b. Deformation
  3. Measurement of dielectric power loss and power factor.

The electrical characteristics represented in the above tests include all that are now known. The problem is to apply them so that unsatisfactory cable may be separated from satisfactory cable without harming the latter. The following discussion on this subject will, in the main, refer only to high-tension cables with paper insulation treated with mineral compound for circuits rated above 12 kv. The results of tests included in this discussion were obtained from commercial cable manufactured prior to Jan. 1, 1924, except as may otherwise be noted.

Insulation Resistance

This subject has been discussed in the complete paper but discussion has been omitted from the abridgement.

Dielectric Strength

The criterion of a satisfactory cable is that it shall successfully operate at its rated voltage in the system to which it is connected and for which it is designed. This requires that every point along the entire length of the cable must be dielectrically strong and continue to be so. The only means now available for determining initially the suitability of a cable as regards dielectric strength is to determine the ultimate dielectric strength of samples of the cable by breaking them down under electrical tension, and then applying a lower electrical tension for a given time to similarly made cables in lengths intended for use, the value and time of application of the test voltage being chosen so as to separate such cable as is dielectrically weak from that which is dielectrically strong without harming the latter. The final criterion for the effectiveness of this test is experience.

The increase in voltage rating of cables has introduced difficulties into the testing procedure of dielectric

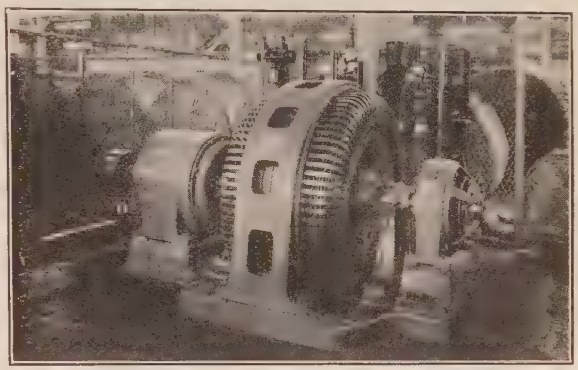

Fig. 4—Sine-Wave Synchronous Motor-Generator Set

Generator rated three-phase, six-pole, 400 kv-a. 12 rev. per min., 900 volts
Motor rated, three-phase, four-pole, 100 h. p., 1200 rev. per min., 550 volts

strength tests, but these are being overcome. At the present time the best samples of single-conductor cable for 66-kv. three phase circuits have a breakdown voltage on short-time test of from 300 kv. to 350 kv., while the best samples of three conductor cable for 33-kv. three phase circuits have a breakdown voltage on short-time test of 200 kv. High-voltage tests in the factory on long lengths of the former cable are conducted at from 100 kv. to 150 kv.; on the latter cable at from 82.5 kv. to 95 kv., the time duration being from 5 min. to 15 min., depending upon conditions. Such values as these require testing equipment of high voltage and high kv-a. rating which must conform to standardized requirements, such that the voltage wave shall "approximate as closely as possible a sine wave." In this phase of the work substantial progress has been made.

Fig. 4 shows a motor-generated set rated 400 kv-a. at 1200 rev. per min. and 900 volts, of which the no-load voltage wave, and the voltage wave when connected through transformers to 1242 feet (three reel lengths)

of 3-conductor 33-kv. cable at 85 kv., are shown in Fig. 5. The characteristics of these waves are:

Load	Deviation Factor	Form Factor
No load...............	1.2%	1.11
Cable load of 1242 ft. of 3-cond. 33-kv. cable at 85 kv........	1.0%	1.11

Fig. 6 shows wave shapes as obtained from a generator which has been in use for cable testing, for 15 years, rated 75 kv-a. at 500 rev. per min. and 550 volts, of which the characteristics are:

Load	Deviation Factor	Form Factor
No load...............	2.8%	1.11_7
Cable load of 702 ft. of 3-cond. 12-kv. cable at 40 kv........	30.9%	1.10_8

Fig. 5—Wave Shapes of Sine-Wave Generator, Rated Three-Phase, 400 Kv-a., 1200 Rev. Per Min., 900 Volts

Upper curve, no-load voltage wave
Lower Curve, voltage wave, Load of 1242 ft., three-conductor, 33-kv. cable at 85-kv.

These comparative values indicate the substantial progress which has been made in the generator design. The excellent characteristics of the waves shown in Fig. 5 for the modern generator are all the more remarkable when it is considered that they are for a load when leading current and of extremely low power factor.

The wave shapes of the modern generators are well within the required limits for testing with sine wave shape and for measuring voltage with a voltmeter following any of the standardized methods, such as through an auxiliary ratio transformer or by means of a voltmeter coil placed in the testing transformer. Ratio transformers being necessarily quite large for use at the high voltages now required, the voltmeter coil placed in the testing transformer becomes a most useful means for making the voltage measurement. A paper on testing transformers has been recently presented to the Institute,[3] in which paper also is included a discussion of voltage measurement together with apparatus available for such measurement.

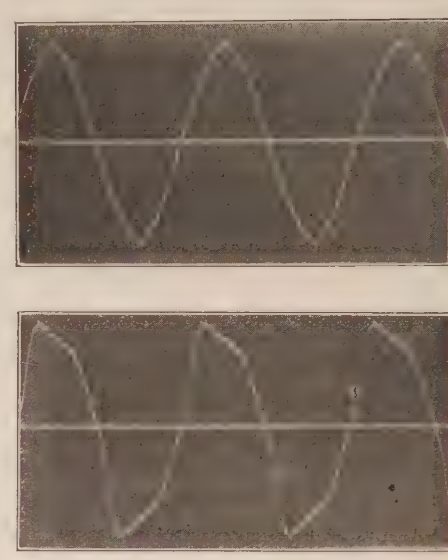

Fig. 6—Wave Shapes of Generator, Rated Three-Phase, 75 Kv-a., 500 Rev. per Min., 550 Volts, in Use for Testing Cable 15 Years Ago

Upper Curve, no-load voltage wave
Lower Curve, voltage wave, load of 702 ft., three-conductor, 12 kv. Cable at 40 kv.

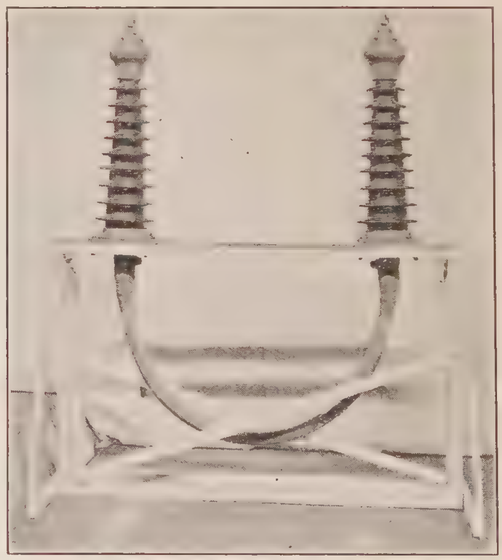

Fig. 7—Two Oil-Filled Cable Terminals, Assembled at hte Ends of a Sample of Cable for a 66-Kv. Three-Phase Circuit, for Ultimate Dielectric Strength Test up to 240 Kv.

Probably the greatest single difficulty confronting the cable tester when making dielectric strength tests is that of applying the voltage to the cable, it being necessary to so prepare the cable ends that they will withstand the high voltage without breakdown or flashover, and so that the break will occur under the

lead and not in the endbell. For tests on reel lengths in the factory where the voltages applied for three minutes are not above 100 kv. between conductors for three-conductor cable or between conductor and sheath for single-conductor cable, the problem is not so difficult, there being several designs of end-bells in use. The usual method is to apply an inverted paper cone to the cable end, which is then filled with petrolatum hot enough to pour. Pressed paper or fibre tubes are frequently placed over the separate conductors of three-conductor cable.

For single-conductor cable where the test voltage is above 100 kv., a most satisfactory means of applying

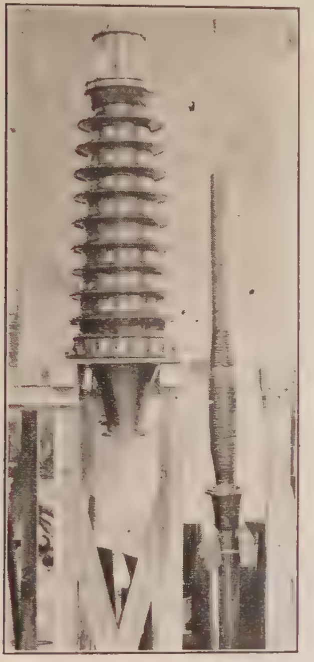

Fig. 8

Fig. 9

Fig. 8—Oil-Filled Cable Terminal, Ready for Assembly to a Sample of Single-Conductor Cable for a 66-Kv. Three-Phase Circuit, for Ultimate Dielectric Strength Test up to 350 Kv.

Fig. 9—Oil-Filled Cable Terminal Assembled to a Sample of Single-Conductor Cable for a 66-Kv. Three-Phase Circuit for Ultimate Dielectric Strength Test up to 350 Kv.

the electrical tension has been found to be through the application of a terminal made of a porcelain oil-filled bushing of standard design provided with suitable fittings for proper application to the cable. Fig. 7 shows two such terminals attached to a sample of single-conductor cable with 30/32 in. treated paper for a 66 kv. three-phase circuit. Terminals such as these have been regularly used in testing reel lengths of single-conductor cable in the factory where the test voltage has been 150 kv. for both five-min. and for 15-min. application; also for ultimate dielectric strength tests up to 240 kv. which is the dry flashover voltage of this terminal. Figs. 8 and 9 show a larger terminal ready for assembling to the cable end, and as assembled to the cable end, the former showing how the cable end is prepared before the terminal is applied. This is done by removing a suitable length of the lead and then building up over the factory insulation with black varnished cloth, covering a portion of this with copper wire or flattened string solder to carry the ground potential of the sheath up over the reinforced insulation a suitable distance to properly distribute the stress. A terminal such as shown in Figs. 8 and 9 has a dry flashover voltage of 350 kv. and if the cable remains sound, it is absolutely satisfactory for use in testing cable samples up to a breakdown voltage of that value. Flashover of the terminal may result at a lower value from disturbances which may occur in the cable, in which event a larger terminal may be used.

A terminal such as shown in Fig. 7 weighs 155 lbs. with fittings, and for a factory test on a reel length at 150 kv., where it is not necessary to build up the cable ends with varnished cloth, it requires the time of two men for two hours to apply the terminals and remove them. A terminal such as shown in Fig. 9 weighs 375 lbs. with fittings, and for an ultimate dielectric strength test where the cable ends must be built up with varnished cloth, it takes two men a day to apply the terminals and remove them. The use of such terminals has made possible satisfactory tests of dielectric strength without the difficulties usually attendant the use of built-up endbells, and represents a most gratifying advance in the art. Suitable terminals are available for the entire range of voltages required in making dielectric strength tests on single-conductor cable.

No satisfactory built-up end-bell has yet been devised for testing 3-conductor cable samples for ultimate dielectric strength where the breakdown voltage is in the order of 200 kv. An average gradient of approximately 250 volts per mil seems to be about the maximum voltage where a built-up endbell following the usual designs can be used in ultimate dielectric strength test of 3-conductor cable with satisfaction. Above this value, breakdown usually results in a crotch failure between conductors in the endbell. Out of 12 samples recently tested where the probable failure would be in the order of 200 kv., every sample failed at substantially lower voltage in the crotch in the endbell, which failures were preceded by excessive leakage over the conductor insulation. Efforts to prevent crotch failures have been made in practise by the use of different filling compounds, such as petrolatum, linseed oil, and transil oil, but as yet without success. The use of long treated paper tubes over the separate conductors has not bettered the results measurably.

Theoretical considerations and calculations indicate that the excessive leakage stress can be kept below safe values only by so designing the external surface of the endbell that it follows essentially the curve of the conductors as they diverge. This is not simple

to do in a built-up end-bell. From a review of all of the factors, it is felt that the best plan is to use a three-conductor oil-filled cable terminal following the practise above suggested for testing single-conductor cable. The early use of such when results will be available for report is contemplated.

Dielectric Power Loss and Power Factor

The measurement of dielectric power loss and power factor of cables for service has in the past been mainly confined to measurements on short samples at voltages up to rated and temperatures up to 100 deg. cent. and on sample reel lengths at rated voltage and temperature of 85 deg. cent.[8] The tendency is to extend these

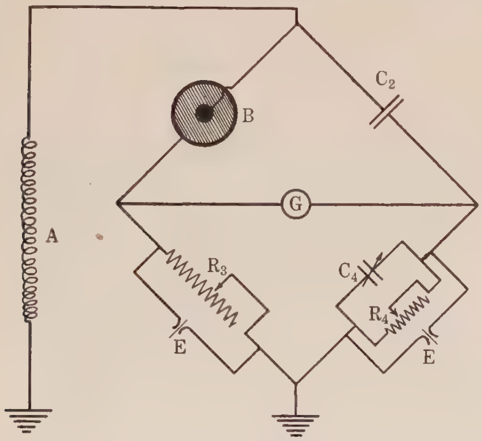

Fig. 17—Diagram of Connections of Schering Bridge.

A—Transformer
B—Cable
C_2 Air Condenser
R_3 Non-Reactive Variable Resistor
R_4 Non-Reactive Variable Resistor
C_4 Variable Air Condenser
G—Galvanometer Detector
E—Safety Gaps

measurements to include each reel length to be shipped, measuring the power factor thereof at room temperature at voltages varying from approximately ½ rated to 2½ times rated. The change in power factor between these voltage limits is noted, the theory being that there should be no change in power factor if the insulation is homogenous, the measurement being made outside of the breakdown voltage range.

Such a measurement requires considerable change in application of the methods previously employed for measuring dielectric power loss and power factor. The means employed and the calculations involved must be simple enough for manipulation by the factory testing personnel under factory working conditions. The range required for cables in use at present is approximately as follows:

Power factor, from 0.002 up, particularly in the range 0.002 to 0.004.
Voltage, 5kv. to 100 kv.
Current, up to 1 ampere, current leading.
Accuracy, power factor to within 0.002.
Frequency, 25 to 60 cycles.

Several methods are applicable to this measurement no one of which is entirely free from objections. One method which gives promise is that of the Schering Bridge, which has been described in various issues of the technical press[9]. The diagram of the connections is shown in Fig. 17. A description of the equipment used in such a set-up, which is proving to be satisfactory, is as follows:

The standard air condenser C_2 is a 3-plate condenser following a design previously described.[10] All of the plates are mounted on a common base and are fixed to give a capacitance of 4×10^{-10} farads. The overall dimensions are 10.5 ft. long, 4 ft. wide, and 7.5 ft. high. The non-reactive resistor R_3 is of high-resistance low-temperature coefficient alloy, wound in two sections connected for minimum reactance. The rated current is 1 ampere, and taps are provided to give approximate resistances of 5, 10, 20, 40 and 60 ohms.

The detector G is unique in that a permanent magnet galvanometer recently developed for detecting alternating currents of low value is used. This is shown in Fig. 18. An ordinary three-stage audio-frequency amplifier is used with the galvanometer, thus giving the desired sensitivity. The galvanometer moving system, entirely immersed in oil, is free from the effects of external vibration so that the required sensitivity is obtained without need for elaborate means of protecting against the effect of external vibration.

The non-reactive variable resistor R_4 is of standard design with a maximum resistance of 11,110 ohms. The variable condenser C_4 is of standard design parts, having a maximum capacitance of 0.16×10^{-6} farads.

The safety gaps consist of two contacts separated

Fig. 18—Permanent Magnet Type of Galvanometer for Detecting Alternating Currents of Low Value

by two cigarette papers, which form of gap has in the past proven effective. Any discharge through the cable or the condenser goes to ground through the break produced in the paper. The standard air condenser in the above set-up has been short-circuited during operation at 50 kv. with no effect on the apparatus or the operator. The entire measuring apparatus, with the exception of the air condenser and detector, is mounted in a glass-covered case with manipulating handles for safety to the operator, extending through.

The operation of the bridge for a given reading is

quite simple. The bridge is balanced by varying R_4 and C_4 until a balance is obtained as noted by the detector. R_3 remains constant for a given range of readings, and the power factor is calculated from the equation,

$$\text{Power factor} = 2\,\pi\,f\,C_4\,R_4$$

where F is the frequency

C_4 is the capacitance in farads of the variable condenser C_4

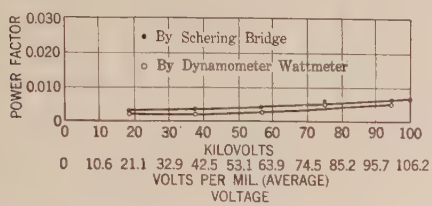

Fig. 19—Variation of Power Factor with Voltage at 25 Deg. Cent. of a 130-ft. Length of Single-Conductor Cable with 30/32-In. Treated Paper Insulation for a 66-kv. Three-Phase Circuit

R_4 is the resistance in ohms of the variable reresistor R_4.

If it is desired to obtain the dielectric power loss, the equation is,

$$\text{Watts} = 2\,\pi\,f\,\frac{R_4}{R_3}\,C_2\,E^2 \quad \text{(power factor)}$$

where, in addition to the factors defined above, R_3 is the resistance in ohms of the resistor R_3, C_2 is the

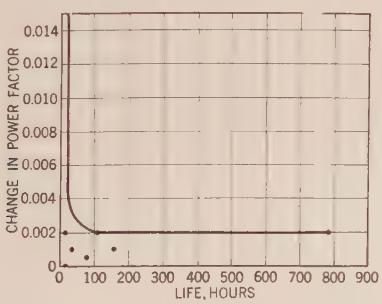

Fig. 21—Relation Between Life of Samples of Treated Paper Cable with 9/32-In. Insulation, Operated at 44-Kv. at 25 Deg. Cent., and Change in Initial Power Factor with Voltage from 27 Volts per Mil. (Average) to Eight-Volts per Mil. (Average) at 25 Deg. Cent.

capacitance of the standard air condenser C_2, and E is the applied voltage in volts.

All methods for making such measurements as the above usually appear well on paper but in operation, factors may be introduced which considerably affect results. The results obtained with the Schering Bridge were, therefore, compared with results obtained on the same cable, by the compensated dynamometer wattmeter method,[10] using two instruments, one of low current rating for determining the necessary compensation with the standard air condenser, the other of higher current rating required when making the measurement on the cable. From results thus obtained, it was found that large errors might be introduced into the bridge reading because of capacitance to ground of the leads from the low voltage side of the standard air condenser and the cable. When effect of this error was reduced to a minimum, results such as shown in Fig. 19 were obtained. These show agreement to within power factor 0.002.

The use of indicating wattmeters alone for such measurements as those described above is highly desirable. The very unique application of a water column of varying temperature to change the resistance of a circuit without changing its reactance, recently described before the Institute[11], has great possibilities. An outfit set up with the "tank," of the wattmeter

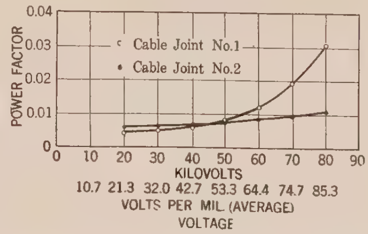

Fig. 22—Power Factor-Voltage Relation at 25 Deg. Cent. of Two Joints of Single Conductor Cable with 30/32 In. Treated Paper Insulation

replaced by a long hose, shielded as suggested by Professor Ryan, to allow of continuous measurement has given promise of perhaps immediate application in measuring small amounts of power.

The effectiveness of the power-factor-voltage test to separate poor cable from good will have to be determined largely from experience. Fig. 21 shows the relation between life and change in initial power factor

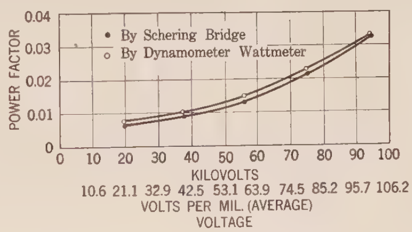

Fig. 23—Power Factor-Voltage Relation at 25 Deg. Cent. of a 100-ft. Length of Single-Conductor Cable with 30/32 In. Treated Paper Insulation Shown by Dielectric Strength Test to be Poor Cable and Unsuited for Use

for several short samples of cable with 9/32 in. treated-paper insulation, operating at 44 kv. While the curve drawn is not definitely located by the points, there is suggestion that a large change in initial power factor indicated short life, while a small change may or may not indicate long life.

Fig. 22 shows the power-factor-voltage relation for two cable joints of single-conductor cable with 30/32 in. paper. Cable joint No. 1 was hand-made and lasted two min. at 175 kv.; cable joint No. 2 was machine-made and lasted 36 hours at 225 kv. Fig. 23 shows the

power factor-voltage relation for a length of cable with 30/32 in. paper shown by dielectric strength test to be poor cable.

A 200-ft. length of cable* similar to that for which the power-factor-voltage curve is shown in Fig. 19, was connected from one line, to neutral of a three-phase 110-kv., 60-cycle commercial circuit, at a voltage from conductor to sheath of 63.5 kv. It operated continuously at no-load for 10 days when failure occurred at a point 30 feet from one end. Examination revealed absolutely no discernible reason for the failure, the cable appearing to be perfect throughout. The defective end was cut from the length, voltage again applied, and same has been running continuously for 90 days. (January 1, 1925).

Testing Installed Cable

The evidence available on the endurance of cable indicates the need of continued testing after the initial tests and installation of the cable. A good example of results obtained by methods departing from those standardized for testing cables has been reported to the Institute[13] by Messrs. Phelps and Tanzer in connection with tests conducted to rate cables after installation. The application of the method of rating by so-called "current-time" curves to low-loss paper-insulated cables has been carried on to a limited extent, with results which, although usually negative, still are of such a nature that the method is not considered to be absolutely inapplicable. This study should be vigorously continued.

Opportunity has been given to test single-conductor cable with 30/32 in. treated paper insulation, known to be poor cable, up to direct voltages of 450 kv. applied for 15 minutes, without evidence of impending failure as shown by current-time curves taken periodically during the test.

Suggestion has been made that high frequency might be utilized for making capacitance or power factor measurements on installed cable, the bridge and generator equipment required being of such a nature as to make it quite easily portable. Table I shows results of capacitance and power factor measurements made at 100 kilocycles on short samples of single-conductor cable with 9/32 in. treated paper insulation before and after endurance life run at 44 kv. The length of life does not seem to be predicted by the value of the initial power factor.

Values of power factor taken after tests with the failure removed show practically no change from initial values.

Several measurements of power factor made at 1000 cycles on cable samples with 30/32 in. treated-paper insulation gave results from which no concord could be noted as regards life. The low voltage, about 25 volts, at which these measurements are made is probably a factor. It is interesting to note, however, that measurements made at 100 kilocycles on cable samples of different kinds of papers showed power factors differing by 50 per cent, though for samples of any given kind of paper, the variations were of the order as shown in Table I. The method appears, therefore, to be of value in detecting different materials, but does not seem to be sensitive to deterioration in a portion of a given material.

TABLE I

Sample	Endurance Test at 44 Kv.		Power Factor at 100 Kilocycles	
	Temperature Deg. Cent.	Life Hours	Before Test	After Test
1	25	77	0.0105	0.0103
2	25	86	0.0103	
3	25	89	0.0106	0.0102
4	85	139	0.0114	
5	85	139	0.0106	
6	85	1055	0.0105	0.0143*
6	85	1055	0.0105	0.0093
7	85	1535	0.0116	0.0102

*Measurement made with failure in sample.

Measurements on other samples made "After Test" were made after cutting out the failure.

*Manufactured after Jan. 1, 1924.

Testing with Direct Current

Experimental work is being continued in the application of direct current to the testing of cables in order that its apparent advantages may be utilized in this field. The large number of d-c. cable-testing sets now in use by the operating companies should allow of accumulation of a considerable amount of data showing the desirability of their use in the field.

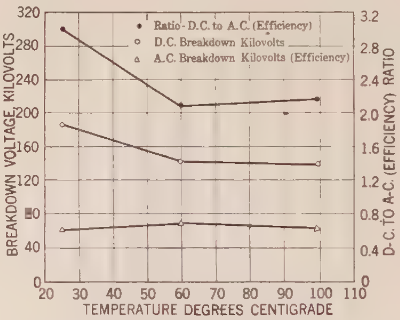

Fig. 27—Relation Between D-C. and A-C. (Effective) Breakdown Voltage Above Ground at Different Temperatures of Three-Conductor 500,000-cm. Sector Cable. with Treated Paper Insulation 9/64 In. on Each Conductor. 1/16-In. Overall Belt.

Fig. 27 shows results of tests made on samples of three-conductor 500,000 cm. sector cable with treated-paper insulation 9/64 in. on each conductor, 1/16-in. overall*. The a-c. breakdown tests were made by starting at 40 kv. applied and held for five min. and then raising five kilovolt each 15 seconds until breakdown. The d-c.-breakdown tests were made by starting at 100 kv. held for five min. and raising five kilovolt

*These samples were supplied by the Commonwealth Edison Co.

each 15 sec. until breakdown. Three tests were made on each section of the cable by applying the test voltage to one conductor with the other two and the lead sheath grounded. In this way each conductor was tested separately from copper to sheath.

These results show a ratio of d-c. to a-c. effective breakdown value somewhat higher than previously assigned from the results available at the time, but the evidence is accummulating that the ratio will increase as the thickness of the material increases. Recent tests on varnished cloth in sheet form up to a thickness of 10 sheets or 120 mils substantiate this conclusion.

Continued experimental work and study of the problem indicates that although for any given breakdown voltage with alternating-current there is a corresponding breakdown voltage with direct-current each of these values depend upon several factors such as the nature and structure of the material, thickness of the material, temperature of the material, shape and size of electrodes, and rate of application of the applied potential. Such a condition obviously prevents standardization of a general value for the d-c. to a-c.-breakdown-voltage ratio, but rather requires that each individual case be considered separately. This confirms what has been pointed out previously.[14]

Conclusions

1. Values of insulation resistance as heretofore obtained are of doubtful worth as a means for distinguishing between satisfactory and unsatisfactory cable.

2. The test for dielectric strength is the most important and the best now available as a suitability test. The difficulties in testing due to the increasing voltage rating of cables are being overcome. Indications are that the present standardized values of test voltage should be increased. Increasing the time of application a few minutes is of doubtful value; a long-time on a sample length has merit. Short-time ultimate dielectric-strength tests should be made on samples taken from reel lengths. The bending tests, as at present, should be continued. Recognition should be given to the fact that many things may happen to the cable after the high-voltage test which this test cannot detect. Hence the advisability of periodic testing at voltages which will not injure sound cable and which will only affect cables where the deterioration has been abnormal.

3. Measurements of dielectric-power loss and power factor are of value, and should be continued. The evidence indicates that good cable will show low dielectric-power loss and power factor, and that the change in power factor of good cable with varying voltage at room temperature will be small. The power-factor voltage test may not always be infallible, however. There is need for standardizing the power-factor voltage test, as regards the nature of the source, the method of connecting same to the cable, the temperature of the cable, and the reporting of the results.

4. Development work towards new methods for testing and rating installed cable during life have not produced new tests which are suitable for superseding those already in use.

5. The increasing use on the part of the operating companies of d-c.-cable-testing sets, together with the experimental work being carried on, should allow of a determination of the most suitable application of direct-current to cable testing that its apparent advantages may be fully utilized.

In closing, the author wishes to acknowledge his indebtedness to others in the General Electric Company who have allowed him to use results of their work in this paper.

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Another New Self-Excited Sychronous Induction Motor

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Synopsis.—*One form of self-excited synchronous induction motor was described by the same author in a paper presented at the Spring Convention of the A. I. E. E., Birmingham, Ala., the present contribution describes a second form of such a motor. The starting, synchronizing, synchronous load and asynchronous overload periods are analyzed with special reference to the synchronizing torque, the automatic compounding and the weight efficiency, and it is shown that this second form is not only capable of duplicating the performance of the first form but of bettering same.*

IN a paper read at Birmingham, Ala., at the 1924 Spring Convention of the A. I. E. E., the writer described the motor diagrammatically shown in Fig. 1, and dealt fully with the theory of this machine during the starting, the synchronizing, the synchronous load and the asynchronous overload periods. It will now be shown how even better results can be achieved in & Burge, relates in the main to synchronous motors and indicates among other things, and quite generally, a very interesting arrangement of windings and brushes which by proper modification and proportioning can, as hereinafter described, be used to cause the unidirectional excitation of such machines to increase with increasing motor load in a practically useful manner.

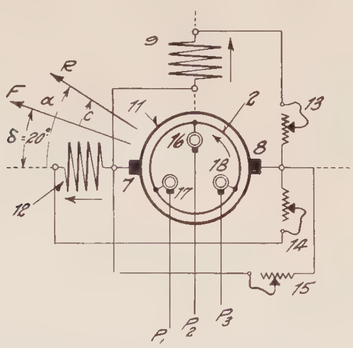

FIG. 1—SELF-EXCITED SYNCHRONOUS INDUCTION MOTOR FYNN FORM NO. 1

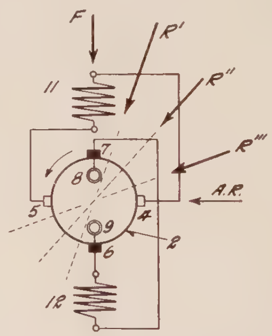

FIG. 2—CROMPTON-BURGE ARRANGEMENT OF EXCITING AND COMPOUNDING CIRCUITS FOR SELF-EXCITED SYNCHRONOUS MOTORS

another way. In order to positively and readily differentiate between the two motors, let us refer to that shown in Fig. 1 as "Form No. 1" and to that here dealt with, as "Form No. 2."

British Patent No. 3227 of 1913, issued to Crompton

The arrangement in question is applicable to single, as well as to polyphase, self-excited synchronous motors and is diagrammatically shown in Fig. 2, its theory, as the writer sees it, can be stated in a few words.

In the two-pole embodiment shown in Fig. 2, the revolving member is the primary, and carries a winding 2 connected to a commutator and capable of being connected to an alternating current supply by means of

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a suitable number of sliprings such as 8, 9. In the figure the commutator is not shown and the brushes co-operating with same are supposed to be resting directly on the commuted winding. The same clarifying expedient is used in all the other figures. There are two sets of brushes 4, 5 and 6, 7, located along axes displaced by 90 electrical degrees. The stationary member carries two coaxial windings 11 and 12, located in the axis of the brushes 6, 7. The winding 11, is connected to the brushes 4, 5, the winding 12 to the brushes 6, 7. The British patent states that the voltage at the brushes 6, 7 is dependent on the cross flux which is approximately proportional to the primary armature reaction *A R*. Winding 11 is referred to as the "shunt" and winding 12 as the "compounding" winding. It will be shown that these terms do not correctly describe the functions of the windings 11 and 12, yet, provided this is understood, they will do as well as any others and will be used hereafter.

During the synchronous operation of the machine shown in Fig. 2, the voltages appearing at the brushes

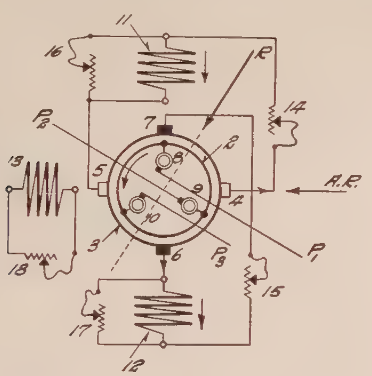

Fig. 3—Self-Excited Synchronous Induction Motor, Fynn Form No. 2

4, 5 and 6, 7 are both unidirectional and their magnitudes depend on the magnitude and space location of the unidirectional resultant motor magnetization *R*. One component of this resultant magnetization is *F* which is due to the arithmetical sum of the unidirectional ampere-turns in 11 and 12, its other component is the unidirectional primary or armature reaction *A R* whose magnitude and space position vary with the load and the power factor of the motor. At no-load *R* may be made to nearly coincide with *F*. As the load increases the angular displacement *c* between *R* and *F* increases. In the case of Fig. 2, where the primary is supposed to revolve counterclockwise, *F* is stationary in space and *R* moves further and further away from *F* as the load increases, progressing in a direction opposed to the rotation of the primary and successively occupying the positions R', R'', R''' and so on. When the primary is stationary, both *F* and *R* revolve synchronously; with increasing load, *F* moves away from *R* in a direction opposed to the rotation of the secondary. At no-load the unidirectional voltage at the brushes 4, 5., is therefore nearly a maximum and it decreases with increasing load. The unidirectional voltage at the brushes 6, 7 is nearly zero at no-load and increases as the load increases. The question arises, can these conditions be utilized in order to secure a satisfactory automatic regulation of the unidirectional excitation of the motor throughout its load range? If so, then can a motor embodying this type of automatic regulation be made to show an acceptable starting, synchronizing and overload performance? What can be done in these respects will be explained in connection with Figs. 3 and 9.

The three-phase, two-pole motor shown in Fig. 3 is a self-excited, synchronous induction motor of Form 2. The primary revolves and carries a winding 2 adapted for connection to the three-phase supply P_1, P_2, P_3 through the sliprings 8, 9, 10, and a commuted winding 3 with which the brushes 4, 5 and 6, 7 located along axes displaced by 90 electrical degrees co-operate. The stationary member, here the secondary, carries the "shunt" and "compound" windings 11, 12 located in the axis of the brushes 6, 7 and the auxiliary winding 13 located in the axis of the brushes 4, 5. The "shunt" winding is connected to the brushes 4, 5 through the adjustable resistance 14 and can be shunted by the adjustable resistance 16. The "compound" winding is connected to the brushes 6, 7 through the adjustable resistance 15 and can be shunted by the adjustable resistance 17. The circuit of the winding 13 can be closed over the adjustable resistance 18. The windings 11 and 12 are connected to magnetize in the same direction, as shown by the arrows placed alongside these windings. The arrow *A R* indicates the general direction of the primary armature reaction.

The auxiliary winding 13, together with the exciting windings 11 and 12, form a polyphase, here two-phase, arrangement of windings on the secondary and the machine can, therefore, be very readily and most effectively started, just like a polyphase slip ring induction motor. In order to facilitate this starting, as well as to gain other advantages, the magnetic circuit is built exactly like that of an ordinary induction motor, without polar projections on rotor or stator and with a very small and uniform air-gap.

In the case of small machines the shunting resistances 16 and 17 can be omitted and one or both of the windings 11 and 12 closed over the commuted winding 2 for use in connection with the winding 13 at starting. The torque is regulated by suitably adjusting the resistances 14, 15 and 18. These resistances are manipulated in exactly the same manner as those in the secondaries of an induction motor. In the case of larger motors, or where small ones have to deal with particularly severe starting conditions, the windings 11 and 12 are closed over the resistances 16 and 17 and the values of the resistances 14 and 15 are kept high during the starting period in order to protect the commutator from the starting currents. When synchronism is nearly reached, the winding 18 is left short-circuited,

but if they have been used the resistances 16, 17 are disconnected and the resistances 14, 15 set to their synchronizing or operating values.

The revolving flux F', produced by the polyphase currents in the primary, always revolves at synchronous speed with respect to the primary and, hence, to the commuted winding 3. As the motor starts, the primary moves in a direction opposed to that in which F' revolves. Since F' must continue to revolve synchronously with respect to the primary, its speed in space, for instance with reference to the secondary windings 11, 12, 13, must diminish as the rotor speed increases. Now the revolution of F' with respect to the secondary windings generates voltages therein, the frequency and magnitude of which diminish with increasing rotor speed, both frequency and magnitude becoming zero when the rotor reaches synchronism. These voltages are responsible for the induction motor torque-producing currents in the secondary windings and cannot synchronize the motor because they approach zero as the rotor speed approaches the synchronous. The amplitude of the voltages generated by F' in the commuted winding 3 remains constant as long as F' is constant because F' always revolves synchronously with respect to 3. The voltages generated in 3 are collected by the brushes 4, 5 and 6, 7. The amplitude of the brush voltages is, therefore, constant but their frequency depends on the speed with which F' moves relatively to said brushes and therefore decreases as the rotor speed increases, becoming zero when the rotor reaches synchronism because F' is then at a standstill.

During the synchronizing period the windings 11 and 12 are not shunted and are connected to the brushes co-operating with the commuted winding. As the induction-motor-torque-producing currents in the secondary windings diminish, the currents due to the slip-frequency brush voltages in the windings 11 and 12 increase, because of the constant amplitude and diminishing frequency of said voltages. These brush currents react with F' and produce a synchronizing torque which brings the rotor into synchronism.

As soon as synchronism is reached the brush currents become unidirectional and provide the unidirectional excitation of the machine through the agency of the windings 11 and 12. As the load changes so does the location of the resultant motor magnetization R change with respect to the axes of the brushes, thus changing the brush voltages. During synchronism, the winding 13 is idle.

When the torque demand is in excess of the maximum synchronous torque of which the motor is capable, the rotor slips out of synchronism and continues to run asynchronously, the windings 11, 12 and 13 again doing duty as polyphase secondaries of an induction motor. Under these conditions the synchronizing torque reappears.

Such in a general way is the mode of operation of the motor, Fig. 3. After what has been said, there can be no difficulty about the conditions to be fulfilled in order to secure a good starting performance. The only question is how are the windings 3, 11 and 12 to be dimensioned in order to secure a sufficiently powerful synchronizing torque and a good compounding characteristic.

To solve the compounding problem it is necessary to divorce one's mind from the idea that 11 is a true shunt and 12 a true compounding winding, and that the voltage at the brushes 6, 7 varies proportionately with the armature reaction. As a matter of fact, increasing load causes the ampere-turns in 11 to diminish and those in 12 to increase. If a compounding action is to be secured the ampere-turns in 12 must increase much faster than those in a true compounding winding would be called upon to increase with increasing load.

Assuming that the motor of Fig. 3 is given the same general design constants as that of Fig. 1, it will be interesting to determine whether or not the performance

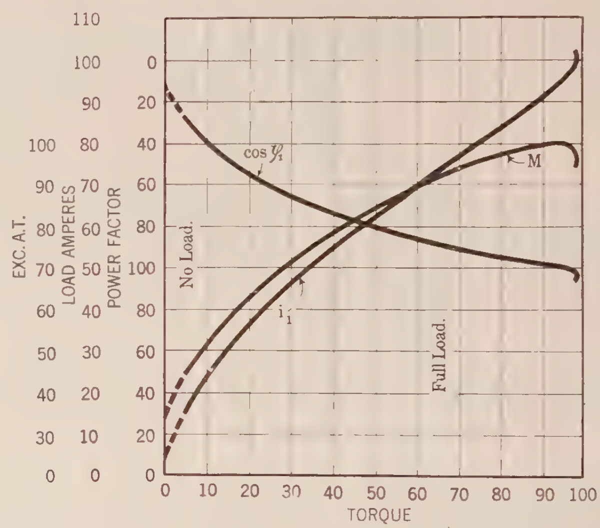

Fig. 4—Synchronous Performance Curves of Fynn Form No. 2 Motor

of the motor of Form 1 can be approached or duplicated by that of the motor of Form 2.

In Fig. 45 of the author's A. I. E. E. paper entitled "A New Self-Excited Synchronous Induction Motor" are given performance curves of a Form 1 motor when designed to produce a certain maximum unidirectional excitation and to operate with its brushes 7, 8 (see Fig. 1 of the present paper), displaced by $\delta = 20$ electrical degrees from the resultant unidirectional magnetization F produced by its secondary windings 9 and 12. With a motor of Form 2 one is able to absolutely duplicate the compounding performance of Form 1. In case the brushes of Form 1 are displaced by δ degrees, this duplication is achieved by so dimensioning the circuits of the windings 11 and 12 of Fig. 3 that when the angular displacement c between F and R is zero the ampere-turns in 11 are proportional to

sin δ, that when c = 90 degrees the ampere-turns in 12 are proportional to cos δ, and that for any value of c the arithmetical sum of the ampere-turns in 11 and 12 of Fig. 3 is equal to the vectorial sum of the unidirectional ampere-turns of Fig. 1. In Fig. 1, when $\alpha = \delta$ then R coincides with F and $c = O$. In Fig. 3 R coincides with F when α is zero. Fig. 4 shows the primary current i_1, the power factor cos ϕ_1 and the exciting ampere-turns M of the Form 2 motor shown in Fig. 3, when the "shunt" and the "compound" windings are dimensioned as just specified. It is seen that the primary current always has a very acceptable

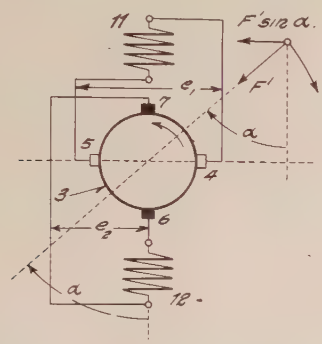

Fig. 5—Showing how the Synchronizing Torque is Produced in Form No. 2 Motor

value although the power factor is leading almost throughout the synchronous operation of the machine, and that the performance of this Form 2 machine at synchronous speed is indeed identical with that of Form 1.

The commuted winding must be dimensioned with an eye to commutation and to the value of the voltages generated in 11 and 12 at the moment of starting. Both considerations lead to the selection of a low brush voltage. Values of 10 to 30 volts will in most cases answer the purpose. It should be noted that at no-load, practically all of the exciting current is supplied through the brushes 4, 5 which then stand near the neutral in so far as the resultant motor magnetization R is concerned. At full load it is the brushes 6, 7 which carry practically all of the exciting current and at that time these brushes also stand near the neutral as referred to R.

Turning to the synchronizing possibilities of Form 2, it is seen that at sub-synchronous speeds the phase of the brush voltage e_2 appearing at the brushes 6, 7, (see Fig. 5), is the same as that of the voltage generated by the primary revolving flux F' in the winding 12 to which the brushes 6, 7 are connected whereas e_1 appearing at the brushes 4, 5 is in phase quadrature with the voltage generated in 11. For these reasons, the brush current conducted into 12 will react with F' to produce a unidirectional and pulsating torque while the brush current conducted into 11 is responsible for a double-slip frequency torque with equal positive and negative maxima. How these torques come to be unidirectional and of double frequency can be recognized with the help of Fig. 5.

If the primary member of the motor revolves counterclockwise, it is because the primary flux F' revolves clockwise. The difference between the speeds of F' and of the rotor is equal to the slip of the latter. F' moves synchronously. In Fig. 5, the flux F' has traveled α deg. from its position of coincidence with the axis of the brushes 7, 6, which position is that from which α is measured. For all values of α between zero and 180 deg., the brush voltage e_2 is of the same direction. To be able to speak of this direction as positive or negative, let it be assumed that the direction which e_2 has in normal synchronous operation is the negative one. The normal synchronous conditions are shown in Fig. 6 for both brush voltages and indicate that for values of α between zero and 180 deg. e_2 is negative. Reference to Fig. 5 shows that for values of α between 180 and 360 deg. e_2 must then be positive. This result has been plotted in Fig. 7 on the simplifying assumption adhered to throughout this paper that all voltages, currents and fluxes vary according to the sine or cosine law. The curve e_2 can also represent the current conducted into the winding 12 since at the very low brush voltage frequency existing near synchronism there is practically no phase difference between voltage and current. The current scale may, of course, differ from

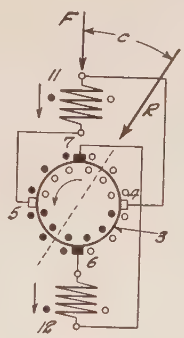

Fig. 6—Showing the Synchronous Distribution and Direction of the Unidirectional Ampere Turns in Form No. 2 Motor

the voltage scale. The brush voltage e_2 and the corresponding brush current are always proportional to sine α. The other factor determining the magnitude of the synchronizing torque is that component of F' which is at right angles to the axis of the winding 12. This component is $F' \times \sin \alpha$ and the resulting positive torque T_{s-12} is, therefore, proportional to sine^2 α. It is unidirectional and pulsating, becoming zero whenever the axis of F' coincides with the axis of the brushes 6, 7 and remaining positive because the polarity of F' with respect to 12 changes concurrently with that of e_2. The maximum amplitude of this torque is proportional to the maximum conduced ampere-turns in 12. For the conditions yielding the performance curves of Fig. 4, the maximum unidirectional

ampere-turns in 12 are proportional to cos 20 deg., which makes the maximum amplitude of T_{s-11} of Fig. 7 proportional to cos 20 deg.

Turning now to the brush voltage e_1 appearing at the brushes 4, 5 and impressed on the secondary 11. By reference to Figs. 5 and 6 it is clear that when $\alpha = 0$ the voltage e_1 is at a negative maximum and becomes zero when $\alpha = 90$ deg. Curve e_1 of Fig. 7 shows its variation throughout a cycle, e_1 is in phase quadrature to e_2 and is always proportional to cos α. Therefore, the brush current due to e_1 is also proportional to cos α and reacts to produce torque with that

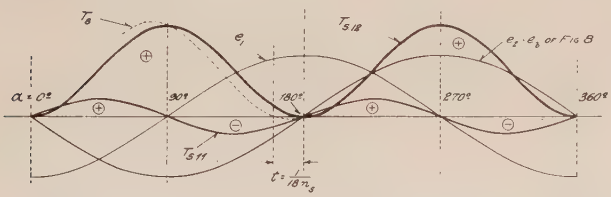

Fig. 7—Synchronizing Voltages and Torques in Fynn Form No. 2 Motor

component $F' \times \sin \alpha$ of F' which is perpendicular to the axis of 11. The resulting torque T_{s-11} is proportional to $F' \times \sin \alpha \times \cos \alpha$ and is of double slip frequency becoming zero whenever F' coincides with the axis of the brushes 4, 5 or with that of the winding 11. For the conditions yielding the performance curves of Fig. 4 the maximum unidirectional ampere-turns in 11 are proportional to sin 20 deg. which makes the maximum amplitude of T_{s-11} of Fig. 7 proportional to ½ sin 20 deg.

The actually available synchronizing torque is the resultant T_s of T_{s-11} and T_{s-12} of Fig. 7 and it is clear that this resultant is substantially unidirectional and therefore highly desirable. It will produce rapid and positive synchronization without tendency to hunt and will not interfere with the asynchronous overload stage of the motor's operation to reduce its maximum asynchronous torque.

It is seen that by making the maximum ampere-turns in 12 greater than the maximum ampere-turns in 11 it is possible to secure a desirable compounding characteristic as well as very favorable synchronizing torque conditions. Here again we find no conflicting requirements to embarrass the designer.

Since the winding 11 does not materially contribute to the synchronizing torque when connected to the brushes 4, 5, its circuit need not be closed at that stage and it can also be left open at starting. However, material increase in synchronizing torque can be secured by temporarily connecting 11 to the brushes 6, 7 and in parallel with 12. To this end, that terminal of 11 which is normally connected to brush 5 is connected to brush 7 and the other to brush 6. This results in a 32 per cent increase in the maximum amplitude of the resultant synchronizing torque. Another way to increase this torque is to dimension 12 for a maximum number of ampere-turns in excess of that required for compounding purposes, reduce these ampere-turns to the desired compounding value by means of the resistance 15 and reduce this resistance to zero during the synchronizing period.

It has already been stated that Form 1 motor of Fig. 1 performs, in synchronous operation, as indicated by the curves of Fig. 4 when the resultant unidirectional magnetization in the motor of Fig. 1 is displaced by 20 electrical degrees with respect to the axis of the brushes 7, 8 of said motor, and its maximum value equals the maximum arithmetical sum of the magnetizations produced by the windings 11 and 12 of Form 2 motor of Fig. 3. To satisfy these conditions, the maximum ampere-turns (disregarding saturation) in windings 9 and 12 of Fig. 1 must be proportional to sine 20 deg. and cos 20 deg. respectively, which means that these ampere-turns are the same as the maximum ampere-turns in windings 11 and 12 of Fig. 3. With this information, the curves in Fig. 8 can at once be plotted. The curve e_b in Fig. 8 must be identical as to phase and magnitude with curve e_2 in Fig. 7, since the machines are identical except for the arrangements and dimensioning of the secondary windings and the number and location of brushes on the commutator. The brush current conducted into the winding 9 of Fig. 1 must yield a double-slip frequency torque T_{s-9} because of the quadrature relation between the axes of its brushes 7, 8 and of its winding 9. The maximum amplitude of this torque is ½ sine 20 deg. and it is therefore identical with T_{s-11} of Fig. 7 except as to sign. The winding 12 of Fig. 1 yields a strictly unidirectional torque proportional to sine² α with a maximum amplitude proportional to cos 20 deg. This maximum amplitude corresponds with the maximum of e_b. Torque T_{s-12}

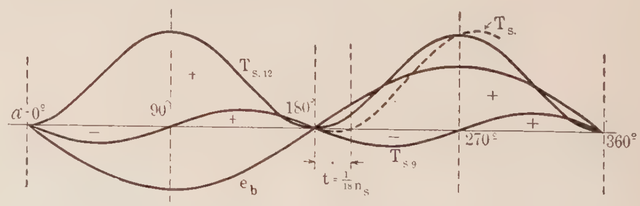

Fig. 8—Synchronizing Voltages and Torques in Fynn Form No. 1 Motor

of Fig. 8 is, therefore, identical with torque T_{s-12} of Fig. 7 as to direction, magnitude and configuration. Part of the resultant synchronizing torque T_s, is dotted into Fig. 8 and is clearly identical with the resultant synchronizing torque of Fig. 7. In both cases it occurs for the same value of c. The amplitude of the negative wave of T_s is less than 3 per cent of the positive one and the latter lasts eight times as long as the former. It is certainly true to say that T_s is substantially unidirectional.

The very interesting conclusion is thus reached that the synchronizing performance and the synchronous characteristics of a motor of Form 1, see Fig. 1 or any

of its modifications, *can be absolutely duplicated* by the motor of Form 2 shown in Fig. 3. No demonstration is necessary to convince anyone that the starting performance of these two machines can be made identical. If the asynchronous characteristics and the synchronizing torques are identical then the asynchronous overload performance of the two machines must also be identical.

But while Form 2, Fig. 3 can do everything that Form 1 Fig. 1 can accomplish, the converse is not true.

It has been pointed out that the synchronizing torque of Form 2 could be materially increased by temporarily connecting winding 11 to the brushes 6, 7. For the compounding characteristic shown in Fig. 4, this change results in an increase of 32 per cent in the resulting synchronizing torque. To duplicate this advantage it would be necessary to temporarily displace the brushes of Form 1 so as to bring their axis into coincidence with the resultant magnetization produced by the windings 9 and 12, a proceeding which is not as practical as a simple change of connections.

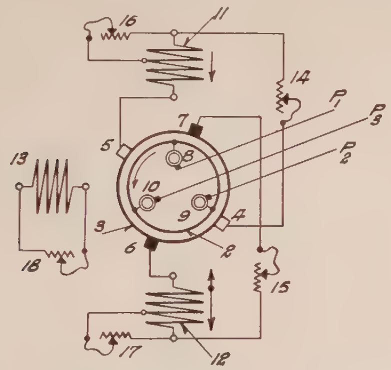

Fig. 9—Self-Excited Synchronous Induction Motor, Fynn Form No. 2

But Form 2 also permits of a wider range of variation in so far as the compounding characteristic is concerned for the reason that said characteristic can be influenced in at least three ways. The ratio of the maximum ampere-turns in 11 and 12 can be varied as explained or by changing the value of e_1 relatively to that of e_2. This is, for instance, achieved by spacing the brushes of one set differently from those of the other. A still wider variation can be brought about by disturbing the quadrature relation of the two sets of brushes or displacing both sets from the position shown in Fig. 3 but without disturbing their quadrature relation.

In the arrangement shown in Fig. 9 the brushes 4, 5 are so placed that e_1 is less than the maximum at no-load and does not reach zero at full load, while the brushes 7, 6 are so located as to make e_2 negative at no load and positive at full load. The result is that the magnetizations due to 11 and 12 oppose each other at no-load and co-operate at full load. No doubt, this example will suffice to indicate the wide range of possibilities afforded by the self-excited synchronous induction motor of Form 2 as illustrated in Figs. 3 and 9. In all cases one secret of success lies in the proper proportioning of the windings 11 and 12 with respect to the limits within which the two brush voltages vary in synchronous and nearly synchronous operation.

The displacement of the brushes from the basic position shown in Fig. 3 also has a bearing on the magnitude and configuration of the synchronizing torque. Just how this torque is affected can readily be stated in general terms. When the axis of the brushes co-operating with the commuted winding on the primary and collecting the synchronizing voltage coincides with the axis of the secondary winding to which said brushes are connected, then the resultant synchronizing torque is unidirectional and pulsating. When said axes are displaced by 90 electrical degrees, in other words, when the phase of the brush voltage conductively impressed on a secondary winding differs by 90 degrees from the phase of the voltage generated in said winding by the synchronously revolving primary flux F', then the resultant synchronizing torque is alternating, of double slip frequency and, all other conditions being equal, of half the amplitude of the pulsating torque. For an intermediate position of the axes under reference the resulting torque has one unidirectional and pulsating and one alternating, double slip frequency component. The nearer the brush and winding axes approach coincidence the larger the unidirectional and the smaller the alternating torque component. It follows that the more the quadrature relation between brush axis and winding axis can be departed from the better for the resulting synchronizing torque. This consideration at once shows one more advantage of the arrangement of brushes shown in Fig. 9.

In so far as the compounding characteristic is concerned, the windings 11 and 12 must be dimensioned with reference to the maximum brush voltages available *within the limits of synchronous operation.* These limits are determined by the travel of R under the influence of increasing load. The measure of this travel is the angle c of Fig. 6. The maximum value of c can usually be made to approach 90 electrical degrees. Reference to Fig. 9 at once shows that, for any value of c up to 90 degrees, the maximum brush voltage available within the limits of synchronous operation can very well be less than the actual maximum. But the *actual maximum* brush voltage *is always* available at sub-synchronous speeds when F' travels with reference to the brush axes and it is seen that this condition is also a factor in determining the obtainable amplitude of the synchronizing torque, in this new motor it makes the brush voltage partially effective for compounding and fully effective for synchronizing purposes.

It will be noted in Fig. 9 that only part of each of the windings 11 and 12 is adapted to be shunted or short-

circuited during the starting operation. Together with the winding 13, one or both of these shunted parts form a two-phase arrangement of windings. Any other combination of windings which provides a polyphase arrangement of windings on the secondary located in inductive relation to the primary can be used in order to insure the starting and the asynchronous overload operation of this motor, which particular one is chosen largely depends on the conditions under which the machine is to operate.

While the embodiments of this new motor chosen for description all have a revolving primary and a stationary secondary, it will be understood that the functions of stator and rotor may be reversed without in any way changing the underlying principles of operation and design.

In view of misunderstandings which have already occurred, and in order to forestall further questions, it should be stated that the author's inventions relating to synchronous induction motors are held by two entirely independent interests, one of which owns all but that covered by U. S. P. 1,337,648.

The Rotating Magnetic Field Theory of A-C. Motors

BY K. L. HANSEN[1]

Associate, A. I. E. E.

Synopsis.—*The predetermination of the performance of a polyphase a-c. machine is greatly facilitated by the fact that at constant voltage and frequency its magnetic field is of constant intensity and rotating with uniform velocity. It is easy to form a mental picture of lines of force moving in space and being cut by conductors, which may be moving or stationary. Furthermore, the rate of cutting, and therefore the generated voltages, which form the basis for quantitative analysis, are readily determined by the relative motion of the flux and the conductors.*

Because of the ease with which a physical conception can be formed of a rotating magnetic field, the idea of considering a single-phase alternating field as made up of two oppositely rotating fields has been found very useful. In a paper entitled "A Physical Conception of the Operation of the Single-phase Induction Motor" TRANSACTIONS A. I. E. E., Vol. XXXVII), Mr. B. G. Lamme has given an excellent description of single-phase induction motor operation based on a conception of two oppositely rotating magnetic fields.

From the discussion of Mr. Lamme's paper, it appears to be the concensus of opinion that the method he uses furnishes the simplest and clearest physical conception of the single-phase motor. However, this is not the method usually employed in the quantitative analysis. Reference to text books will show that the mathematical treatment is usually based on the so called "cross field" theory. In this method the secondary induced voltage is considered made up of two components, one the voltage induced by transformer action of the alternating field and the other the voltage generated by rotation of the secondary conductors in the magnetic field.

It has been argued against the method based on two oppositely rotating fields, also known as the "Rotating Field" theory, that it is more apt to lead to erroneous results, requires more expert handling and that it is an indirect method, being based on the previously determined performance of the polyphase motor. However, the main argument against it seems to be its limitation to induction motors only, and that it must be abandoned when we come to motors of the commutator type. Even those who otherwise favor the method appear to agree that it is not applicable to commutator motors as we are then no longer dealing with induction machines, but with shunt or series motors, as the case may be.

The objection to the rotating field theory, that it is applicable to induction motors only, would be a serious one if it were valid. However, it will be shown in this paper that the theory can be readily applied to commutator machines also, and that so far from being more apt than other methods to lead to erroneous results, it undoubtedly furnishes the simplest and most direct means for mathematical deductions in the more complicated problems where three or more circuits are inductively related and moving with respect to one another.

General Discussion

In its general form, the a-c. motor comprises one or more stationary circuits and one or more rotating electric circuits inductively related to the stationary circuits. Energy is transferred from the stationary to the rotating circuits through the medium of a common magnetic field. In this discussion the magnetic field is in general considered the resultant of two fields rotating in opposite directions. These two components are not necessarily equal, in fact one of them may vanish and the resultant is then a uniformly rotating field, as for example in a polyphase machine. Only motors in which the magnetic reluctance is uniform in all directions will be considered, that is, motors with projecting poles are not included.

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There are then two main groups of motors to be discussed; the induction type, in which the rotor circuits are short-circuited upon themselves; and the commutator type, in which the rotor circuits are either short-circuited or connected to an external circuit through a commutator. A number of essential features are common to both types. Thus, at any speed, the m. m. fs. of the rotor rotate with velocities which, combined with the velocity of mechanical rotation, are always equal to the velocities of the stator fields. The common magnetic field is produced by an m. m. f., which is the vector sum of the stator and rotor m. m. fs.

When running at any slip, s, there are in general two voltages induced in the rotor circuits of frequencies $s\,f$ and $(2 - s)\,f$, according to whether it is induced by the field rotating in the same or in opposite direction to the

rotation of the rotor, where f is the stator frequency. In magnitude the induced voltages are, of course, proportional to their respective frequencies. As this viewpoint obviously eliminates the necessity of considering the rotational and transformer voltages separately, the solution of many problems are greatly simplified thereby. The torque developed by either field is also readily determined, it being in all cases the product of the field, the m. m. f. of the rotor circuits revolving in the same direction as the field and the sine of the angle between them.

As already stated, the voltages induced in the rotor circuits are of frequencies $s\,f$ and $(2 - s)\,f$. In the induction type the rotor currents resulting from these voltages are likewise of frequencies $s\,f$ and $(2 - s)\,f$. However, in the commutator type the resulting rotor currents are at all speeds converted by the commutator into line frequency. In their magnetic reactions the rotor currents become fixed in space by the commutator and the rotor circuits can therefore be considered as remaining stationary in every respect, except as regards the magnitudes of the induced voltages, which are determined by the frequencies of slip, as pointed out.

The rotor currents becoming fixed in space by the commutator is the cause of some essential differences in the operation of the induction and commutator types. Thus, in the induction machine, the reactance of the rotor circuit changes with the slip, while in the commutator type it is the same at all speeds. Also, by shifting the brushes on the commutator, the relative position of the stator and rotor m. m. fs. is changed so that the voltages that are induced in the stator circuits by the rotor currents may be advanced or retarded in time. This becomes of importance when an external e. m. f. is impressed on the rotor as it introduces the possibility of power factor correction.

The subject of power factor correction has lately been the object of considerable discussion and the readiness with which the rotating field theory lends itself to the analysis of just such problems, involving a displacement angle between the stator and rotor currents is another marked advantage of this method. Application of the method to the analysis of some proposed schemes for power factor correction will be taken up in the mathematical section.

However, before taking up the mathematical discussion, it will be shown by way of illustration how readily the method can be applied to the much discussed problem of calculating the performance of a single-phase induction motor.

Consider a single-phase motor and a two-phase motor of the same constants per circuit as the single-phase machine. Then if E be the impressed voltage and I_p the current per phase of the two-phase motor at slip s, the apparent impedance per phase is $Z_a = \dfrac{E}{I_p}$. Similarly, if I_b is the current per phase when running backwards at the same speed, the apparent impedance at slip $(2 - s)$ is $Z_b = \dfrac{E}{I_b}$. It is then shown in the appendix that the apparent impedance of the single-phase motor at slip s is $Z_s = \dfrac{Z_a + Z_b}{2}$ and the current of the single-phase motor is $I_s = \dfrac{E}{Z_s}$. Let T_a = torque of two-phase motor at slip s and T_b = torque at slip $(2 - s)$. The torque developed in the single-phase motor at slip s by the field revolving in the same direction as the rotor then is $T_1 = \left(\dfrac{e_1}{E}\right)^2 \times T_a$, where $e_1 = \dfrac{Z_a I_s}{2}$, and the torque developed by the oppositely rotating field $T_2 = \left(\dfrac{e_1}{E}\right)^2 \times T_b$, where $e_2 = \dfrac{Z_b I_s}{2}$. The resultant torque of the single-phase motor at slip s, $T_s = T_1 - T_2$. Herefrom the remaining quantities, power, efficiency and power factor can be determined directly. Thus, by extremely simple calculations the performance of a single-phase motor is derived from the performance of a two-phase motor of same constants per circuit. Which one of the numerous methods that have been devised for calculating the performance of a two-phase motor to use is, of course, a matter of choice.

When it is desired to calculate the performance from the running and locked test readings, the locked single-phase readings can be used directly in calculating the two-phase performance. The single-phase no-load reading with the rotor short-circuited, that is, running light, can not be so used, because the exciting admittance per phase of the two-phase motor is then a little more than one half the single-phase admittance, or, what amounts to the same thing, the two-phase no-load impedance per phase is almost twice the single-phase no-load impedance. The amount by which the two-phase impedance falls short of being exactly twice the single-phase no-load impedance is obviously the apparent impedance per phase when running backwards at full speed. Since this latter impedance is almost independent of the exciting current it can readily be determined to a high degree of accuracy. On the basis of the modified single-phase no-load reading the diagram of the two-phase motor can be constructed and the single-phase performance calculated therefrom.

As a numerical example, the following readings have been taken on a single-phase motor;

Running Light		Rotor locked
110	Volts	110
3.2	Amperes	14.8
78	Watts	982
$\cos\phi_0 = 0.221$	P. F.	$0.603 = \cos\phi_L$
Primary resistance		2.36 Ohms

The no load impedance per phase $Z_0 = \dfrac{110}{3.2} = 34.4.$

$R_0 = Z_0 \cos \phi_0 = 7.6 \quad X_0 = Z_0 \sin \phi_0 = 33.6$
It is known that the two-phase no-load impedance per phase is slightly less than $2\,Z_0$, or the magnetizing current a little more than one half of 3.2 amperes. To determine how much $2\,Z_0$ should be reduced, construct a diagram, using the observed readings, except that the magnetizing current is reduced to approximately one half, say 1.7 amperes.

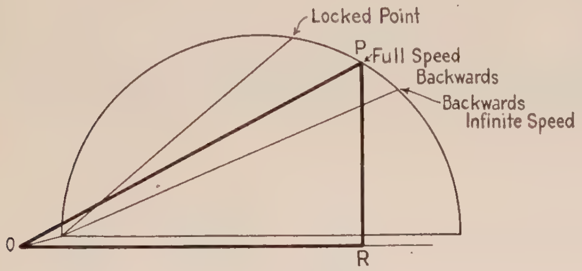

Fig. 1

No refinements are necessary in the construction of the diagram to modify the no load readings and the simple diagram as shown in Fig. 1 is sufficient. From the current triangle $O\,P\,R$ in this diagram the apparent impedance at slip = 2 is found to be $Z_b = \dfrac{110}{16.5} = 6.67.$

$R_b = Z_b \cos \phi_b = 3.2$ and $X_b = Z_b \sin \phi_b = 5.85.$ Subtracting R_b from $2\,R_0$ leaves 12, and X_b from $2\,X_0$ leaves 61.35, hence the corrected no load impedance per phase is $\sqrt{12^2 + 61.32^2} = 62.5$. The no-load

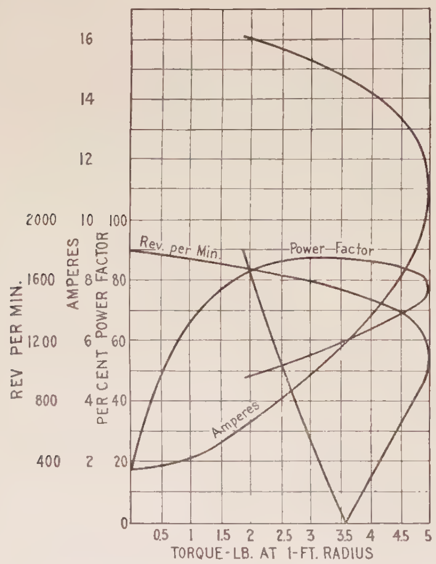

Fig. 2

values to use in calculating the two-phase performance are therefore 1.76 amperes and 0.192 power factor. Fig. 2 shows the curves of the two-phase motor. Then at some speed, for example 1600 rev. per min., we find,

Forward rotation 4.67 amperes, 0.872 power factor
Backward rotation 16 amperes, 0.49 power factor.

$Z_a = \dfrac{110}{4.67} = 23.55 \quad R_a = 23.55 \times 0.872 = 20.55 \quad X_a = 23.55 \times 0.488 = 11.50$

$Z_b = \dfrac{110}{16} = 6.87 \quad R_b = 6.87 \times 0.49 = 3.37 \quad X_b = 6.87 \times 0.87 = 5.97$

Adding 23.92 17.47

Dividing by 2 11.96 8.735

Single-phase current $I_s = \dfrac{110}{\sqrt{11.96^2 + 8.735^2}} = 7.43$ amperes at 0.81 power factor.

$e_1 = \dfrac{23.55 \times 7.43}{2} = 87.4 \quad e_2 = \dfrac{6.87 \times 7.43}{2} = 25.5$

$T_1 = \left(\dfrac{87.4}{110}\right)^2 \times 2.875 = 1.808$ lb. at 1 ft. radius.

$T_2 = \left(\dfrac{25.5}{110}\right)^2 \times 2.05 = 0.110$ lb. at 1 ft. radius.

$T_s = T_1 - T_2 = 1.698$ lb. at 1 ft. radius

equals resultant single-phase torque at 1600 rev. per min The complete single-phase performance is shown in Fig. 3.

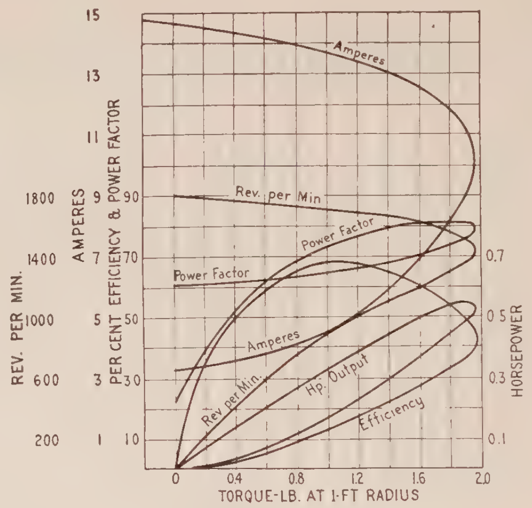

Fig. 3

In this simple method it may be of interest to note the absence of complicated geometrical figures, trigonometric transformations, inversions, equivalent circuits, empirical coefficients, etc., in which the quantitative analysis of the single-phase motor usually abounds. Furthermore, it will be seen in the appendix that a conception of two oppositely rotating fields immediately furnishes sufficient data to write down one set of equations, the solution of which forms the basis of the method described.

To further illustrate the usefulness of the conception of rotating magnetic fields the mathematical analysis will be extended to the somewhat more involved problems of phase conversion and power factor correction.

Appendix

Mathematical Expression for Two Oppositely Rotating Fields

A current with maximum value I and varying periodically according to the cosine law is usually

represented by the expression $I \cos \omega t$, where $\omega = 2\pi f$, f being the frequency. Using the exponential form of the cosine, a sinusoidal current may be represented by a pair of rotating vectors, that is $I \cos \omega t$ may be written $\frac{I}{2}\epsilon^{j\omega t} + \frac{I}{2}\epsilon^{-j\omega t}$. Many cumbersome trigonometric expressions and transformations are frequently avoided by the use of this notation (see for example "Radio Communication," by John Mills). That the expression $\frac{I}{2}\epsilon^{j\omega t}$ represents a vector revolving in counter-clockwise direction with angular velocity ω is readily seen by writing

$$\frac{I}{2}\epsilon^{j\omega t} = \frac{I}{2}(\cos \omega t + j \sin \omega t)$$

and assigning to t a series of increasing positive values. The expression

$$\frac{I}{2}\epsilon^{-j\omega t} = \frac{I}{2}(\cos \omega t - j \sin \omega t)$$

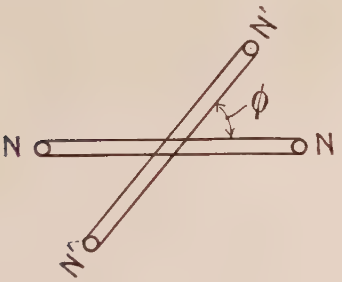

FIG. 4

is likewise seen to represent a vector of same length and revolving in clockwise direction. In Fig. 4 let a current $I \cos \omega t$ be flowing in a coil $N\,N$ of n turns. The instantaneous value of the m. m. f. of the coil then is $n\,I \cos \omega t$ or in the above notation

$$\frac{n\,I}{2}\epsilon^{j\omega t} + \frac{n\,I}{2}\epsilon^{-j\omega t}$$

As the m. m. f. is a directed quantity in space the first term of this expression represents a m. m. f. of constant intensity $\frac{n\,I}{2}$ rotating in positive direction, and the second term represents a m. m. f. of same intensity rotating in opposite direction. Let the coil $N-N$ be turned through an angle of ϕ radians in positive direction and its m. m. f. becomes

$$\frac{n\,I}{2}(\epsilon^{j\omega t} + \epsilon^{-j\omega t})\,\epsilon^{j\phi} = \frac{n\,I}{2}\epsilon^{j(\omega t+\phi)} + \frac{n\,I}{2}\epsilon^{-j(\omega t+\phi)}$$

that is, the m. m. f. revolving in positive direction has been advanced ϕ radians and the m. m. f. revolving in negative direction has been retarded ϕ radians.

The most striking feature of the polyphase system, that it can produce a rotating magnetic field of constant intensity, is most readily deduced by use of this notation. To illustrate, assume m coils, symetrically based on a cylindrical core, the space angle being $\frac{2\pi}{m}$ radians. The coils are excited by currents I, differing in phase by $\frac{2\pi}{m}$ radians. The m. m. f. of the k^{th} coil then is

$$\frac{n\,I}{2}\left[\epsilon^{j(\omega t+\frac{2\pi k}{m})} + \epsilon^{-j(\omega t+\frac{2\pi k}{m})}\right]\epsilon^{j\frac{2\pi k}{m}}$$

and the total m. m. f. of all the coils is

$$\sum_{0}^{m\text{-}1} k\,\frac{n\,I}{2}\left[\epsilon^{j(\omega t+\frac{2\pi k}{m})} + \epsilon^{-j(\omega t+\frac{2\pi k}{m})}\right]\epsilon^{j\frac{2\pi k}{m}}$$

$$= \sum_{0}^{m\text{-}1} k\,\frac{n\,I}{2}\epsilon^{j(\omega t+\frac{4\pi k}{m})} + \sum_{0}^{m\ 1} k\,\frac{n\,I}{2}\epsilon^{-j\omega t}\,\epsilon^{ok}$$

$$= \frac{m\,n\,I}{2}\epsilon^{-j\omega t} \text{ since } \sum_{0}^{m\text{-}1} k\,\frac{n\,I}{2}\epsilon^{j(\omega t+\frac{4\pi k}{m})} = 0$$

That is, the resultant m. m. f. is of constant intensity $\frac{m\,n\,I}{2}$ and rotating in negative direction. If the sign of either time angle or space angle be changed the resultant m. m. f. is seen to rotate in opposite direction.

In Fig. 4, let Z_m be the mutual impedance between coils $N\,N$ and $N'\,N'$ when in coaxial position. The voltage induced in the coil $N'\,N'$ by the current flowing in $N\,N$ then is $Z_m I$. When $N'N'$ is turned ϕ radians in positive direction the voltage induced by the positively rotating field of $N\,N$ is retarded ϕ radians and becomes $\frac{Z_m I}{2}\epsilon^{-j\phi}$ and the voltage induced by the negatively rotating field is advanced ϕ radians and becomes $\frac{Z_m I}{2}\epsilon^{j\phi}$. The voltage induced by both fields is

$$\frac{Z_m I}{2}\epsilon^{-j\phi} + \frac{Z_m I}{2}\epsilon^{j\phi} = Z_m I \cos \phi$$

SINGLE-PHASE INDUCTION MOTOR

The rotor circuits of the single-phase induction motor being short-circuited upon themselves in all directions constitute a polyphase system and for convenience will be considered two-phase with constants determined accordingly. Assume the rotor to be revolving at slip s and consider its direction of rotation positive. Using the customary notation let $Z_m = r_m + j\,x_m$ = Mutual inductive impedance between stator and rotor circuits.

$Z_0 = r_0 + j\,x_0$ = Self inductive impedance of primary

$Z_1 = r_1 + j\,s\,x_1$ = Self inductive impedance to rotor current of frequency $s\,f$. x_1. x_1 = secondary reactance at standstill in terms of primary

$Z_2 = r_1 + j\,(2 - s)\,x_1$ = Self inductive impedance to rotor current of frequency $(2 - s)\,f$

E = volts impressed on primary

I_s = Primary current

I_1 = Positively rotating component of rotor current

I_2 = Negatively rotating component of rotor current

The voltages induced in the primary then are:

by the primary current $I_s = (Z_m + Z_0)\,I_s$

by the positively rotating rotor current $Z_m\,I_1$

by the negatively rotating rotor current $Z_m\,I_2$

the currents I_1 and I_2 being two-phase have full inductive effect. The sum of these voltages equals the impressed volts, hence,

$$(Z_m + Z_0)\,I_s + Z_m\,I_1 + Z_m\,I_2 = E$$

The voltages induced in the rotor are:

by the positively rotating component of primary current

$$\frac{s\,Z_m\,I_s}{2}$$

by the positively rotating component of rotor current

$$(s\,Z_m + Z_1)\,I_1$$

by the negatively rotating component of primary curren

$$\frac{(2 - s)\,(Z_m)\,I_s}{2}$$

by the negatively rotating component of rotor current.

$$[\,(2 - s)\,Z_m + Z_2]\,I_2$$

The sums of voltages of frequencies $s\,f$ and $(2 - s)\,f$ are separately equal to zero, hence

$$\frac{s\,Z_m\,I_s}{2} + (s\,Z_m + Z_1)\,I_1 = 0 \text{ or } s\,Z_m\,I_s + 2\,(s\,Z_m + Z_1)\,I_1 = 0 \text{ and}$$

$$\frac{(2 - s)\,Z_m\,I_s}{2} + [\,(2 - s)\,Z_m + Z_2]\,I_2 = 0 \text{ or}$$

$$(2 - s)\,Z_m\,I_s + [\,(2 - s)\,Z_m + Z_2]\,I_2 = 0$$

The e. m. f. equations of primary and secondary are then

$$\left.\begin{aligned} (Z_m + Z_0)\,I_s + Z_m\,I_1 + Z_m\,I_2 &= E \\ s\,Z_m\,I_s + 2\,(s\,Z_m + Z_1)\,I_1 &= 0 \\ (2 - s)\,Z_m\,I_s + 2\,[\,(2 - s)\,Z_m + Z_2]\,I_2 &= 0 \end{aligned}\right\} \qquad (1)$$

Solving these equations

$$I_s = \frac{E\,2\,\{\,s\,(2 - s)\,Z_m^2 + (2 - s)\,Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2\}}{2\,Z_0\{s(2 - s)Z_m^2 + (2 - s)Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2\} + Z_m\,\{(2 - s)\,Z_m\,Z_1 + s\,Z_m\,Z_2 + 2\,Z_1\,Z_2\}} \qquad (2)$$

$$I_1 = \frac{-\,E\,s\,Z_m\,[(2 - s)\,Z_m + Z_2]}{2\,Z_0\{s(2 - s)Z_m^2 + (2 - s)Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2\} + Z_m\{(2 - s)\,Z_m Z_1 + s\,Z_m\,Z_2 + 2\,Z_1\,Z_2\}} \qquad (3)$$

$$I_2 = \frac{-\,E\,(2 - s)\,Z_m\,(s\,Z_m + Z_1)}{2\,Z_0\{s(2 - s)Z_m^2 + (2 - s)Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2\} + Z_m\{(2 - s)\,Z_m\,Z_1 + s\,Z_m\,Z_2 + 2Z_1\,Z_2\}} \qquad (4)$$

The equations of a two-phase motor of same constants per phase are easily found to be

$$(Z_m + Z_0)\,I_0 + Z_m\,I_1' = E$$
$$s\,Z_m\,I_0 + (s\,Z_m + Z_1)\,I_1' = 0$$

where I_0 = primary current per phase and I_1' = secondary current.

Here from

$$I_0 = \frac{E\,(s\,Z_m + Z_1)}{s\,Z_m\,Z_0 + Z_m\,Z_1 + Z_0\,Z_1} \qquad (5)$$

$$I_1' = \frac{-\,E\,s\,Z_m}{s\,Z_m\,Z_0 + Z_m\,Z_1 + Z_0\,Z_1} \qquad (6)$$

The apparent impedance per phase of the two-phase motor at slip s then is

$$Z_a = \frac{E}{I_0} = \frac{s\,Z_m\,Z_0 + Z_m\,Z_1 + Z_0\,Z_1}{s\,Z_m + Z_1}$$

The apparent impedance at same speed rotating backwards is

$$Z_b = \frac{E}{I_0} = \frac{(2 - s)\,Z_m\,Z_0 + Z_m\,Z_2 + Z_0\,Z_2}{(2 - s)\,Z_m + Z_2}$$

Adding the apparent impedances of both rotations

$$Z_a + Z_b = \frac{s\,Z_m\,Z_0 + Z_m\,Z_1 + Z_0\,Z_1}{s\,Z_m + Z_1} + \frac{(2 - s)\,Z_m\,Z_0 + Z_m Z_2 + Z_0\,Z_2}{(2 - s)\,Z_m + Z_2} =$$

$$\frac{2\,Z_0\{s(2 - s)Z_m^2 + (2 - s)Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2\} + Z_m\{(2 - s)Z_m Z_1 + s\,Z_m\,Z_2 + 2\,Z_1\,Z_2\}}{s\,(2 - s)\,Z_m^2 + (2 - s)\,Z_m\,Z_1 + s\,Z_m\,Z_2 + Z_1\,Z_2}$$

Comparing with (2) it will be seen that the apparent impedance of a single-phase motor at slip s is one half the sum of the apparent impedances of a two-phase motor of same constants at slips s and $(2 - s)$. Furthermore, if the impedance drop $\frac{Z_a\,I_s}{2}$ be substituted for E in (6) the result is identical with (3), showing that the low frequency component of secondary current is equal to the two-phase secondary current at this reduced voltage. Similarly, the high frequency component of secondary current is seen to be equal to the two-phase secondary current at slip $(2 - s)$ and the voltage reduced to $\frac{Z_b\,I_s}{2}$. The torque components of the single-phase motor in positive and negative directions are likewise seen to be equal to the torques of the two-phase machine at corresponding slips and reduced voltages.

It follows therefore that in calculating the performance by the graphical method there is no need of a special diagram for the single-phase motor, the same diagram being applicable to both polyphase and single-phase motors.

Induction Phase Converter

In applications where it is essential to obtain polyphase power from a single phase supply an induction phase converter is often used to effect the desired transformation. The converter consists essentially of a single-phase induction motor with a tertiary circuit on the stator displaced at a certain angle from the primary circuit. Thus, in Fig. 5, R is the rotor of a single-phase motor, P_1 the primary winding and P_2 the tertiary winding displaced 90 deg. in positive direction from P_1. P_2' is one phase of a load circuit, on which it is desired to impress a voltage in quadrature

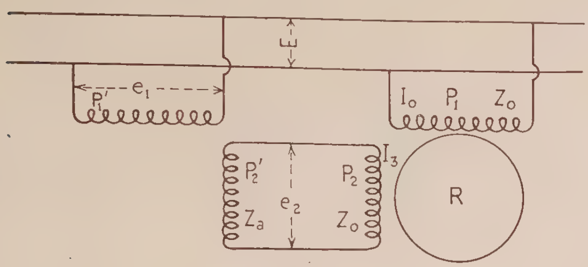

Fig. 5

to the voltage on the other phase, P_1', and as nearly as possible equal to it in magnitude. In Fig. 6 is shown a phase converter with the primary connected in series with one of the load phases, as distinguished from the shunt connection of Fig. 5.

Using the same notation as before, the mutual and self inductive impedances of the tertiary circuit are respectively equal to the mutual and self inductive impedances of the primary Z_m and Z_0. Let Z_a be the impedance per phase of the load circuit and let $Z_0' = Z_a + Z_0$. The speed being very close to synchronous, the forwardly rotating component of secondary

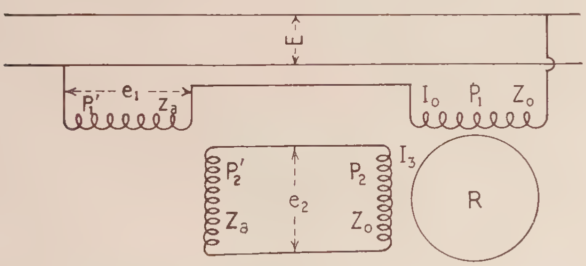

Fig. 6

current can be neglected, that is $I_1 = 0$. The voltage generated in the tertiary circuit by the backwardly rotating component of secondary current is 90 deg. ahead of the voltage generated by this current in the primary circuit and is, therefore, $Z_m I_2 \epsilon^{j\frac{\pi}{2}} = j\, Z_m I_2$. The double-frequency voltage generated in the secondary by the current in the tertiary circuit is likewise seen to be $Z_m I_3 \epsilon^{-j\frac{\pi}{2}} = -j\, Z_m I_3$.

From Fig. 5 is then readily obtained

$$\left.\begin{aligned} (Z_m + Z_0)\, I_0 + Z_m I_2 \qquad\qquad &= E \\ Z_m I_0 + (2\, Z_m + Z_2)\, I_2 - j\, Z_m I_3 &= 0 \\ j\, Z_m I_2 + (Z_m + Z_0')\, I_3 \qquad &= 0 \end{aligned}\right\} \tag{7}$$

Solving

$$I_0 = \frac{E\,[Z_m^2 + Z_m Z_2 + 2\, Z_m Z_0' + Z_2 Z_0']}{(Z_m + Z_0)[Z_m Z_2 + 2\, Z_m Z_0' + Z_2 Z_0'] - Z_m^2 Z_a} \tag{8}$$

$$I_2 = \frac{-\,E\,(Z_m^2 + Z_m Z_0')}{(Z_m + Z_0)[Z_m Z_2 + 2\, Z_m Z_0' + Z_2 Z_0'] - Z_m^2 Z_a} \tag{9}$$

$$I_3 = \frac{j\, E\, Z_m^2}{(Z_m + Z_0)[Z_m Z_2 + 2\, Z_m Z_0' + Z_2 Z_0'] - Z_m^2 Z_a} \tag{10}$$

$$e_2 = Z_a I_3$$

Denoting the denominator by D, it is interesting to note that the first term of I_0 is $\frac{E\, Z_m^2}{D}$, which, com-

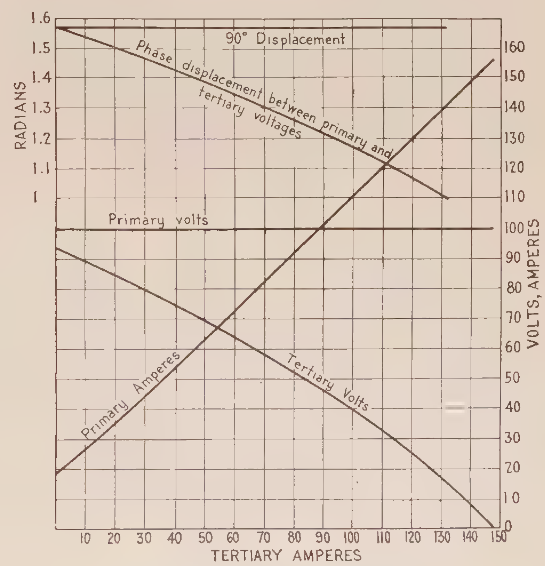

Fig. 7

bined with $I_3 = j\, \frac{E\, Z_m^2}{D}$ produces a m. m. f. rotating backwards, which is balanced by the first term of I_2, which is equal to $\frac{-\,E\, Z_m^2}{D}$. It is, therefore, the double frequency component of secondary current which increases with increasing load on the tertiary circuit. In Fig. 7 are shown the curves of a shunt connected converter of the following constants: $Z_0 = 0.05 + j\, 0.15$ $Z_2 = 0.05 + j\, 0.03$ $Z_m = 0.975 + j\, 9.9$ $E = 100$. Z_a is assumed to vary so as to maintain a constant power factor of 80 per cent.

For the series-connected converter is obtained the following equations from Fig. 6:

$$\left.\begin{aligned} (Z_m + Z_0')\, I_0 + Z_m I_2 \qquad\qquad &= E \\ Z_m I_0 + (2\, Z_m + Z_2)\, I_2 - j\, Z_m I_3 &= 0 \\ j\, Z_m I_2 + (Z_m + Z_0')\, I_3 \qquad &= 0 \end{aligned}\right\} \tag{11}$$

and here from

$$I_0 = \frac{E\,[Z_m^2 + Z_m Z_2 + 2\,Z_m Z_0' + Z_2 Z_0']}{(Z_m + Z_0')\,[Z_m Z_2 + 2\,Z_m Z_0' + Z_2 Z_0']} \qquad (12)$$

$$I_2 = \frac{-\,E\,(Z_m^2 + Z_m Z_0')}{(Z_m + Z_0')\,[Z_m Z_2 + 2\,Z_m Z_0' + Z_2 Z_0']} \qquad (13)$$

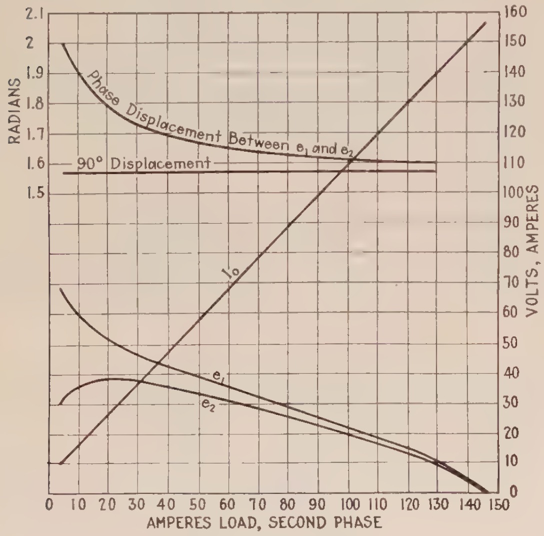

FIG. 8

$$\frac{j\,E\,Z_m^2}{(Z_m + Z_0)\,[Z_m Z_2 + 2\,Z_m Z_0' + Z_m Z_0']} \qquad (14)$$

$e_1 = Z_a I_0 \quad e_2 = Z_a I_3$

In Fig. 8 are shown the curves of the same converter shown in Fig. 7, except that it is connected in series. It will be noted that with the series connection the phase voltages of the load circuit tend towards equality in magnitude and quadrature relation in phase as the load increases, while the reverse is true for the shunt connection.

REPULSION MOTOR

As illustration of the application of the method to commutator motors, consider the repulsion motor shown diagramatically in Fig. 9. It being at the present merely intended to show that the rotating field theory is applicable to commutator motors also, only the plain repulsion motor will be considered, although the method can be readily extended to the various forms of compensated motors, and to include the phenomena of brush short-circuit currents.

In Fig. 9 let the brushes be shifted λ radians in positive direction from the line $A\,B$, which is the position of maximum mutual inductive effect between stator and rotor circuits. As in the single-phase induction motor, there are two voltages generated in the secondary of frequencies s and $(2 - s)$. However, the currents resulting from these voltages are converted by the commutator into line frequency at all speeds, and consequently combine into one secondary current. The voltage induced in the primary by the positively rotating component of the secondary current is advanced λ radians in phase, and the voltage generated by the negatively rotating component is retarded λ radians. The voltage equation of the primary is, therefore,

$$(Z_m + Z_0)\,I_0 + \frac{Z_m I_1}{2}\,\epsilon^{j\lambda} + \frac{Z_m I_1}{2}\,\epsilon^{-j\lambda} = E$$

Similarly the voltage equation of the secondary is seen to be

$$Z_m\left[\frac{s\,\epsilon^{-j\lambda}}{2} + \frac{(2-s)\,\epsilon^{j\lambda}}{2}\right] I_0 + \left[\frac{s\,Z_m}{2} + \frac{(2-s)\,Z_m}{2} + Z_1\right] I_1 = 0$$

Substituting

$$\epsilon^{j\lambda} = \cos\lambda + j\sin\lambda$$
$$\epsilon^{-j\lambda} = \cos\lambda - j\sin\lambda$$

and the voltage equations reduce to

$$\left.\begin{aligned} (Z_m + Z_0)\,I_0 + Z_m \cos\lambda\,I_1 &= E \\ Z_m[\cos\lambda + j(1-s)\sin\lambda]I_0 + (Z_m + Z_1)I_1 &= 0 \end{aligned}\right\} \qquad (15)$$

Solving

$$I_0 = \frac{E\,(Z_m + Z_1)}{[Z_m^2 + Z_m Z_0 + Z_m Z_1 + Z_0 Z_1] - Z_m^2 \cos\lambda\,[\cos\lambda + j\,(1-s)\sin\lambda]} \qquad (16)$$

$$I_1 = \frac{-\,E\,Z_m\,[\cos\lambda + j\,(1-s)\sin\lambda]}{[Z_m^2 + Z_m Z_0 + Z_m Z_1 + Z_0 Z_1] - Z_m^2 \cos\lambda\,[\cos\lambda + j\,(1-s)\sin\lambda]} \qquad (17)$$

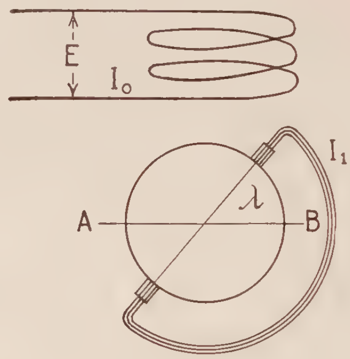

FIG. 9

The exciting current of the positively rotating field

$$I_0' = \frac{I_0\,\epsilon^{-j\lambda} + I_1}{2}$$

$$= \frac{Z_1\,\epsilon^{-j\lambda} - j\,(2-s)\,Z_m \sin\lambda}{2\,\{[Z_m^2 + Z_m Z_0 + Z_m Z_1 + Z_0 Z_1] - Z_m^2 \cos\lambda\,[\cos\lambda + j\,(1-s)\sin\lambda]\,\}} \qquad (18)$$

The exciting current of the negatively rotating field

$$I_0'' = \frac{I_0\,\epsilon^{j\lambda} + I_1}{2}$$

$$= \frac{Z_1 \epsilon^{j\lambda}}{2 \{[Z_m^2 + Z_m Z_0 + Z_m Z_1 + Z_0 Z_1]}$$

$$\frac{+ j s Z_m \sin \lambda}{- Z_m^2 \cos \lambda [\cos \lambda + j (1 - s) \sin \lambda] \}} \quad (19)$$

The voltage induced by the positively rotating field

$$e_1 = I_0^1 X_m \epsilon^{-j(\frac{\pi}{2} + \psi)}$$

and the voltage induced by the negatively rotating field

$$e_2 = I_0'' X_m \epsilon^{j(\frac{\pi}{2} - \psi)},$$

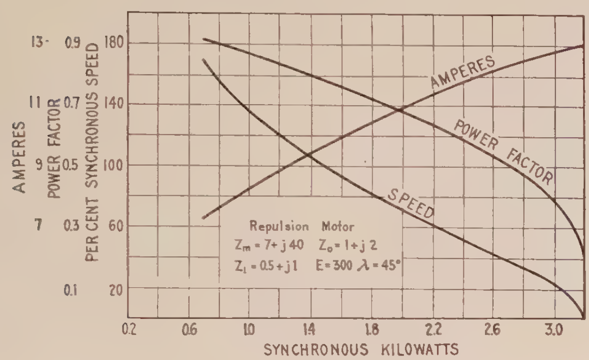

Fig. 10

where ψ is the angle by which the exciting current leads the true magnetizing current

The torque developed by the positively rotating field $T_1 = e_1 I_1 \cos \omega_1$, ω_1 = phase angle between e_1 and I_1.

The torque developed by the negatively rotating field $T_2 = e_2 I_2 \cos \omega_2$, ω_2 = phase angle between e_2 and I_2.

Resultant torque $= T_1 + T_2$.

Fig. 10 shows the curves of a motor of constants $Z_m = 7 + j\,40$ $Z_0 = 1 + j\,2$ $Z_1 = 0.5 + j\,1$ $E = 300$ $\lambda = 45$ deg.

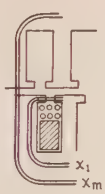

Fig. 11

Power Factor Compensation

To further illustrate the application of the above method to commutator motors, it may be of interest to consider the case where one of the rotating fields vanishes, that is the symmetrical polyphase motor. There is, apparently, an increasing demand for means of correcting power factor on inductive loads, and the use of commutators in connection with induction motors may, therefore, become of considerable importance in the near future. In Steinmetz's "Theory and Calculation of Electrical Apparatus" (Pages 52-92 and page 379) are discussed a number of methods of power factor compensation.

The simplest and most economical of the various methods proposed appears to be the so-called Heyland motor. In addition to the ordinary squirrel-cage, the rotor of the Heyland motor is supplied with a compensating winding connected to a commutator and usually placed in the same slots as the rotor bars. By means of brushes bearing on the commutator, a voltage of suitable magnitude and phase is impressed on the compensating winding.

With the compensating winding placed in the same slots as the rotor bars, practically all of the cage leakage reactance becomes a part of the mutual reactance between the cage and the compensating winding. The impedance of the cage Z_1 can, therefore, be considered as consisting of the resistance, r_1, only. The mutual impedance between the cage and the compensating winding, $Z_m' = Z_m + j\,x_1$, where Z_m is the mutual impedance between the primary winding and the cage, and also the mutual impedance between

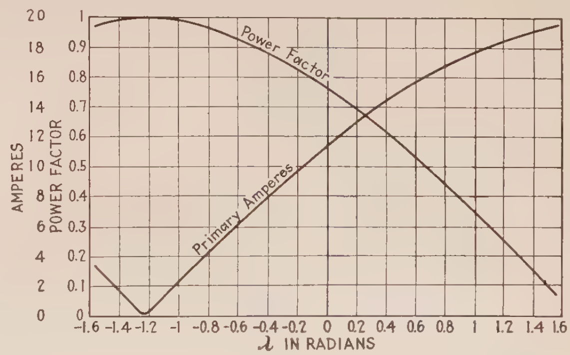

Fig. 12

the primary and the compensating winding reduced to primary terms. $Z_2 = r_2 + j\,x_2$ is the impedance of the compensating winding in terms of primary, x_2, which is the reactance of the leakage flux around the end windings, remains constant at all speeds.

Let I_0, I_1 and I_2 be the current in the primary, the the squirrel cage and the compensating winding, respectively, all in terms of primary. With the brushes shifted λ radians in positive direction, and a voltage $c\,E$ impressed on the commutator, the voltage equation of the three circuits are

$$\left.\begin{aligned} (Z_m + Z_0)\, I_0 + Z_m I_1 + Z_m \epsilon^{j\lambda} I_2 &= E \\ s\, Z_m I_0 + (s\, Z_m' + Z_1)\, I_1 + s\, Z_m' \epsilon^{j\lambda} I_2 &= 0 \\ s\, Z_m \epsilon^{-j\lambda} I_0 + s\, Z_m' \epsilon^{-j\lambda} I_1 + (s\, Z_m' + Z_2)\, I_2 &= c\, E \end{aligned}\right\} \quad (20)$$

solving

$$I_0 = \frac{E \{ s\, Z_m' (Z_1 + Z_2)}{s(Z_1 + Z_2)\, [Z_m' (Z_m + Z_0) - Z_m^2]}$$

$$\frac{+ Z_1 Z_2 - c\, Z_m Z_1 \epsilon^{j\lambda} \}}{+ Z_1 Z_2 (Z_m + Z_0)} \quad (21)$$

$$I_1 = \frac{-sE\{Z_m Z_2 + c\,[Z_m'(Z_m + Z_0) - Z_m^2]\,\epsilon^{j\lambda}\}}{s(Z_1 + Z_2)\,[Z_m^1(Z_m + Z_0) - Z_m^2] + Z_1 Z_2 (Z_m + Z_0)} \qquad (22)$$

$$I_2 = \frac{sE\{c\,[Z_m'(Z_m + Z_0) - Z_m^2] - Z_m' Z_1 \epsilon^{-j\lambda}\} + c\,E\,Z_1(Z_m + Z_0)}{s(Z_1 + Z_2)\,[Z_m'(Z_m + Z_0) - Z_m^2] + Z_1 Z_2 (Z_m + Z_0)} \qquad (23)$$

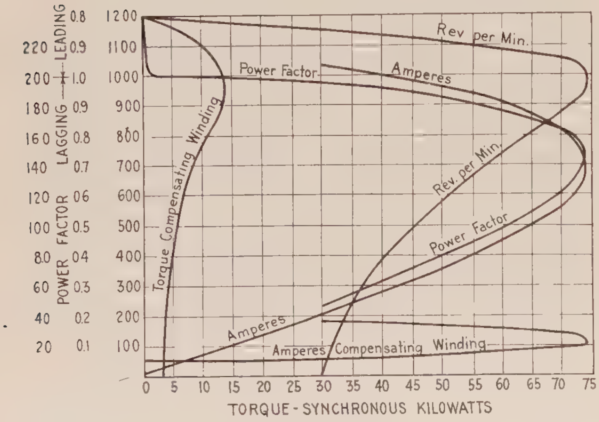

FIG. 13

The exciting current

$$I_0' = I_0 + I_1 + I_2\,\epsilon^{j\lambda} =$$

$$\frac{E\{s(Z_1 + Z_2)(Z_m' - Z_m) + Z_1(Z_2 + c\,Z_0\,\epsilon^{j\lambda}\}}{s(Z_1 + Z_2)[Z_m'(Z_m + Z_0) - Z_m^2] + Z_1 Z_2 (Z_m + Z_0)} \qquad (24)$$

$$e_1 = X_m I_0'\,\epsilon^{-j(\frac{2}{\pi} + \phi)} \qquad e_2 = x_m I_0'\,\epsilon^{-j(\frac{\pi}{2} + \phi + \lambda)}$$

$$T_1 = e_1 I_1 \cos\omega_1 \qquad T_2 = e_2 I_2 \cos\omega_2$$

Resultant torque $T = T_1 + T_2$

At synchronism $s = 0 \quad I_1 = 0$ and

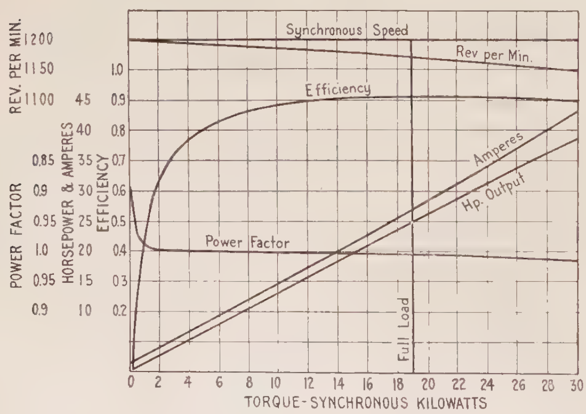

FIG. 14

$$I_0 = \frac{E\,(Z_2 - c\,Z_m\,\epsilon^{j\lambda})}{Z_2\,(Z_m + Z_0)} \qquad (25)$$

$$I_2 = \frac{c\,E}{Z_2} \qquad (26)$$

From formula (**25**) it will be seen that I_0 becomes equal to zero when c and λ are so chosen that $Z_2 = c\,Z_m\,\epsilon^{j\lambda}$. However, to get complete compensation when loaded the motor must be somewhat over compensated at no-load.

As illustration a 25 h. p. 3 phase 440 volts star connected motor has the following constants

$Z_m = 2.5 + j\,25$ $Z_m' = 2.5 + j\,25.6$ $Z_0 = 0.2 + j0.56$
$Z_1 = 0.3$ $Z_2 = 1 + j\,0.25$

Letting $c = 0.0415$, Fig. 12 shows the no-load values for different brush positions. Figs. 13 and 14 show the speed-torque curves and performance over the operating range when c is increased to 0.0435 and λ fixed at $-$ 1.3 radians.

FRENCH ELECTRIFICATION PROGRESS

Among the achievements in the field of production and distribution of electric current in 1923 are the completion of a part of the installations at 150,000 volts of the railroads of the Midi, the commencement of the construction of the great feeder at 150,000 volts of the Orleans Railway, the substantial enlargements of the generating stations serving the region of Paris, the putting into service of the State system at 45,000 volts in the north of France, the completion of new sections of the Paris subterranean lines at 60,000 volts, and the beginning of construction of several lines at 120,000 volts, notably those which will transmit to Lyons the energy produced by the Viclaire plant in the Alps.

There are at present in France 8,900 kilometers of high-tension lines, of which 5000 kilometers carry between 45,000 and 90,000 volts, while the remaining 3900 carry a voltage higher than 90,000.

ELECTRIFICATION OF THE FRENCH RAILROADS

Considerable progress has been made in France since the war in the replacement of steam with electric motive power on some of the railroads. The systems of the Midi and the Orleans are at present the most actively engaged in this transmission work, and it is predicted that the tracks of the latter system between Paris and Orleans will be electrically equipped within the next five years. An order for 30 large electric locomotives has been placed by a French railroad with an American concern, and deliveries of various kinds of electric apparatus for railway use are being constantly made. The widespread employment of electricity in French industrial plants is being rapidly followed by its adoption for traction purposes.

The partial electrification in progress will not greatly modify the economic situation. The total consumption of coal by the railroads (8,500,000 metric tons in 1919), represents only 15 or 16 per cent of the entire fuel demand of the country, and less than half its annual deficit. The achievement of the partial railroad electrification program should not decrease this deficit by more than two or three million metric tons.

Discussion at Spring Convention

LIGHTNING ARRESTER APPLICATION FROM THE ECONOMIC STANDPOINT[1]

(Atherton)

Birmingham, Ala., April 8, 1924

K. B. McEachron: In the fourth paragraph in the first page, the statement is made that the relief voltage of the aluminum arrester for 6.6-kv. service is 18 kv., and for a certain distribution arrester is 28 kv. In the next paragraph is stated that the station type auto-valve has a relief voltage of 21 kv. instantaneous value. It is also stated that the comparison is well shown by the curves in Fig. 1. If the relief voltage is taken as that at which current first begins to flow then, according to the figure referred to, the distribution type (Curve 2) has a relief value of zero volts and the type *S V* and *L V*, 10 and 24 kv. respectively. From an examination of the curves, is it not true that these curves do not represent test results, but rather calculated curves based on theoretical considerations It is stated that the station type "closely parallels the electrolytic and therefore no curve is shown." As shown, however, this cannot be the case, since as stated in Mr. Atherton's paper before the Institute in 1923, the arrester is designed for a so-called counter voltage of 25 per cent above the crest value of the rated voltage of the arrester. In this case, this gives about 13,000 volts, which is the value given in the paper. It should be remembered that this critical voltage is without the series line gap which adds materially to the voltage at which discharge begins.

At 60 cycles this increase may amount to 25 per cent or more, while with a steep wave front a still larger multiplying factor is usually required. In this connection I would like to have Mr. Atherton explain how the value of 21 kv. is obtained.

Curves, such as shown in Fig. 1, are misleading unless it is stated that the values are based on assumed theoretical conditions, and that they cannot represent operating results because the series gap—always used—has been omitted.

It is desirable to correct an erroneous impression as to the characteristics of the multigap arrester, which may be inferred by a study of Fig. 1. Curve 2 represents the volt-ampere characteristics of a 400-ohm fixed resistance. In practise the resistance used in many thousands of arresters is not constant as assumed by Mr. Atherton, but is reduced to a fraction of its 110-volt resistance when subjected to high-voltage steep-wave-front impulses. This means that in actual operation the instantaneous voltage at the higher currents will be very much less than indicated and is not correctly represented by a straight line. Well designed arresters of this type compare very favorably with the valve type of arresters when compared on the basis of instantaneous voltages during discharge. There are other features of the gap-resistance type which make it inferior to the valve types.

In making this study of the economics of lightning-arrester application Mr. Atherton finds it necessary to make certain assumptions. Among other things he states that the type *S V* arrester may be considered as giving perfect protection. For the purpose of this paper any other arrester might have been used or perhaps better yet a hypothetical arrester which might be called arrester No. 1 and the arrester giving half protection designated as arrester No. 2. It has not been established that any type affords the assumed protection, nor do I believe that the art has yet been developed to such a point that no failures in service can occur.

The experience of Mr. Roper in Chicago, referred to in the paper, shows that increasing density of the arresters results in decreased losses of apparatus. In general until the number of arresters exceed the number of transformers the best results will be secured by placing an arrester at each transformer. If additional arresters are required it is probable that the greatest benefit will be obtained by placing the additional protection along the line rather than placing several arresters in parallel at one transformer installation.

In making tests using impulse voltages to determine arrester characteristics, it is well to bear in mind, that laboratory tests will, in general, give varying results, and to be directly compared, all the tests should be made on the same impulse generator. Tests made by different investigators, should be compared with caution.

It is also true that although a line is drawn as the volt-ampere characteristic of an arrester, as a matter of fact, with present-day testing methods, the curve is a broad band whose width is determined by two factors. The first is the inherent variation between arresters and the second is the range of division of sparking on the measuring spheres. These variations do, in some cases, produce a deviation of as much as 10 per cent above and below the average curve.

A. L. Atherton: Mr. McEachron's comments and questions in regard to Fig. 1, "Volt-ampere relations showing comparative performance characteristics of several arrester types," merely point out that such a characteristic does not indicate the relief voltage, or voltage at which the discharge starts, and to this extent such curves fail to give a complete indication of protection value. Since the lightning-arrester performance is discontinuous, the relief voltage cannot be shown on the curve of operating characteristics, but must be covered by a separate statement, as I have done.

The value of 21 kv. cited, is merely the crest value of double-line voltage which is fairly representative of this type arrester. This value is secured by test and, since the time lag is very small, it is not very greatly different for power frequencies and for steep wave fronts.

Volt-ampere characteristic curves of lightning arresters as determined by present-day testing practice will not be precise, but will, as Mr. McEachron has stated, cover a band of considerable width, due not only to variations in the testing procedure and measurements, but also to variations in the product. A central line, however, clearer to use, and, if the limitations are recognized, just as dependable.

PAPERS ON OIL CIRCUIT BREAKERS

(Scholz[1], Mac Neill[2], Hilliard[3], Jenks[4])

Birmingham, Ala., April 9, 1924

J. D. Hilliard: On Mr. Jenk's paper, I heartily concur in his final conclusions that the operator has not determined his breaker needs. It seems to me rather absurd that the whole line of stations should be held to the expense of building a breaker at a definite rating, to take care of the severe conditions of some particular circuit. It seems to me the thing to do is to get after the particular circuit and ease up on the condition.

He mentions, in his various types of breakers, the series break, but it is a debatable question whether the series break has any advantage over the ordinary breaker.

"The manufacturer has not fitted himself, by research work, to meet the operator's needs." That, with the General Electric Company, has been done away with; we have fitted ourselves.

"The operator and manufacturer have not co-operated to develop, operate and service breakers as they should." That is undoubtedly true, and there should undoubtedly be many more tests made in the field than have been made in the past.

A series of tests was made upon plain-break and explosion-

1. A. I. E. E. Journal, Vol. XLIII, September, p. 813.

1. A. I. E. E. Journal, Vol. XLIII, May, p. 436.
2. A. I. E. E. Journal, Vol. XLIII, September, p. 818.
3. A. I. E. E. Journal, Vol. XLIII, May, p. 430.
4. A. I. E. E. Journal, Vol. XLIII, August, p. 715.

chamber breakers, and operating in the same plant, with the same mechanism, by the same generator, under the same circuit connections and load. Broadly speaking, we found that in that particular test the maximum amount of gas with the explosion chamber at 1200 amperes, at 63,000 volts, was about one-third of the minimum amount with the plain break; that the maximum amount with the explosion chamber was about one-tenth of the maximum amount with the plain break. With increased duty the explosion-chamber breaker has a speed increase due to the increased pressure in the explosion chamber. The plain breaker, shows very little change in speed. Whatever change there will be, however, in the plain-break breaker is a decrease in speed, rather than an increase. That comes from the increased pressure in the tank acting upon the rod passing through the tank, and also upon other factors which all tend to decrease the speed of operation. The rod passing through is acting as a piston, and the force on that piston is acting opposite to the force of acceleration given by the spring and this tends to slow up the breaker.

A series of tests was made recently by the A. E. G. Company of Germany to determine arc duration. In a two-break explosion-chamber breaker at 80,000 volts the longest arc duration was 9 half cycles on a 50-cycle circuit; at 70,000 volts the arc duration

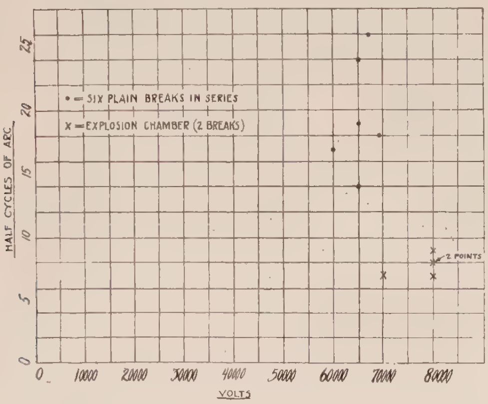

FIG. 1—ARC DURATION IN PLAIN-BREAK AND EXPLOSION-CHAMBER OIL CIRCUIT BREAKERS

Arc duration with different voltages at 50 cycles per minute. The length of time is given in half cycles. The plain-break breaker has six plain breaks in series; speed, 5 m. per sec.; amperes, 234-290. The explosion-chamber breaker has two breaks; speed, 3.23 m. per sec.; amperes, 330-410.

was about 7 half cycles. In the plain-break breaker, with six breaks in series the maximum arc duration at about 67,000 volts was 25 half cycles. These tests bear out the tests we have made in Schenectady very closely.

J. B. Mac Neill: In the years 1913 and 1914, the Westinghouse Company had available, due to cancellation by a large customer a 15,000-kv-a. low-reactance alternator on which a considerable number of tests were made in our factory. Our experience since has indicated that the results of those tests were to some extent not borne out by subsequent field tests.

We account for that by the inherent rapid decrement characteristic of a single machine when subjected to short circuit. This decrement takes place in the short-circuit current and also in the terminal voltage, so that the arc kv-a. delivered to the breaker decreases approximately as the square of either current or voltage.

Mr. Hilliard's remarks regarding the tests at the General Electric factory are very interesting. I was surprised, in looking over his paper and in looking over my paper, to see the apparently relatively large concentration of power that was available at Bessemer for the Westinghouse 44,000-volt tests. Mr. Hilliard draws the conclusion that the power available was not adequate to stress either the plain-break or the explosion-chamber breakers. We reached 3600 amperes at 44,000 volts, and that would seem to me to be adequate power for those purposes.

On page 4 of Mr. Hilliard's paper, regarding the ability of the breaker to withstand the shock of oil throw, in 1915 the Westinghouse Company, in conjunction with the Detroit Edison Company, made a series of tests at the Connors Creek Station, where there was available approximately 12,000 amperes at 24,500 volts on short circuit which still stands as one of the highest power tests ever made. At that time the conditions in the top chamber of the breaker, the possibility of breaking castings due to the upward impact of the oil, and more especially the actual explosion in the top chamber, of gases hot enough to ignite with oxygen, were rather fully gone into before the tests were over.

In 1920, we made at our factory, under the direction of our Research Department, a series of tests involving bombs. Those tests were under the direction of Mr. Escholz and Dr. Rodman, and were of considerable interest and some help in determining breaker structures. The particular difficulty with those tests was controlling the rate of propagation of the disturbance, but by certain investigations of powder proportions the results of which were mixtures which burned with different rates of rapidity, it was possible to simulate in some way the action that obtains in high-power breakers.

I just wanted to add to Mr. Hilliard's comment on the bottom of page 4 regarding secondary explosions, that they are nearly always caused by static sparks. Cases are on record where these explosions were caused by hot gases such as hydrogen igniting with the oxygen in the top chamber and not static sparks, though undoubtedly there are cases where static sparks are the cause of the trouble.

On the subject of oil viscosity, the Westinghouse Company has conducted a series of researches in the last two years on the subject of oil viscosity and has found that the question of flash-point has been much overstressed as affecting circuit-breaker operation. We have found that the lighter oils of late years have given very successful operation in breaker structures. Dr. Rodman has been in charge of those experiments. Briefly, years ago the high flash-point oils did not contain the same proportion of highly volatile matter that the lighter oils did, but due to the activity of the people who make gasoline nowadays those extremely volatile constituents are removed, with the result that the lighter oils are now by us considered adequate and even superiod to the heavier oils for circuit-breaker use. You will be interested to know that within the last year we have therefore standardized for indoor circuit breakers on the use of transformer oil.

In my paper, I deal somewhat with the extremely high reestablished voltages experienced at Bessemer on the 44,000-volt system. These are probably due to the fact that this 44,000-volt system is not as completely grounded as the 110,000-volt system and this in the minds of our engineers accounts for the tremendous kick we got upon opening the arc. It is doubtful whether anything of the same magnitude of these same voltage kicks can be obtained unless there is connected up a large high-voltage system with many transformers and interconnected lines which have a tendency to cause surges and re-establish the arc.

W. E. Mitchell: I am glad that we have had two types of papers presented here, because the two sides of the story must work out together to get the right answer. We have had the operator's viewpoint and we have had the manufacturer's viewpoint, and only as these two are co-ordinated will we get a satisfactory answer.

I think that the design is absolutely the function of the manufacturer. About all the operator can do—and it is what he should do, as Mr. Hilliard and Mr. MacNeill both brought out—is to the best of his knowledge and ability give the facts to the

manufacturer as to what he requires. But, gentlemen, when that is all said and done, what we want are circuit breakers that will open the circuits, exactly as we want transformers that will stand the bumps.

If I had any criticism to make of the manufacturers, it would be that they have in the past years spent too much time trying to convince the operators that what they had manufactured was exactly right, and there was nothing whatever wrong with it—instead of correcting obvious faults that have been brought out in operating practise. It may have been the operator's fault; he may have put the switch in a place where the duty was a little too severe, but after all, what we must have are oil circuit breakers so rugged in design that they will stand some abuse.

Today the oil circuit breaker is immeasurably better than it was three or four years ago, but it still has altogether too much trigger work and too many jim-cracks on it. When you have to come down to adjusting breakers to two thousandths or four thousandths of an inch, to get them to operate properly, and if when you fail to do that you break the operating rods or links, or something else, it is too delicate a piece of mechanism to give to the ordinary electrician. We are not running a laboratory; we are giving service to our customers and what we must have are very rugged switches. As I looked through one of the factories a month ago and saw some of the changes that have been made, getting away from the old elliptical tank which was formerly used to a round, welded tank with cast steel tops of such construction that it would not blow up every time there was an explosion, I felt much better; and I realized that really great advances have been made in the past four years. We must get switches that won't be wrecked when opening a short circuit.

Probably you can come back from a design standpoint and say, "Tell us exactly what duty you want," and I will admit we ought to tell you, but only within broad limits, gentlemen. We want to get things simplified into big classes. Then we want the switches to come onto our system so that we can work them, so that ordinary men and not factory men can put them up, can repair them and can give service to the people whom we are supposed to give service to with them.

J. M. Oliver: On the Alabama Power Company's system considerable trouble has been caused by secondary explosions in oil circuit breakers, especially in those of rather old design. There were several instances in which the breaker ruptured the circuit without very much evidence of distress and probably a minute after the opening, due to some unknown cause, an explosion would occur which practically wrecked the switch. We believe that oil circuit breakers should be designed to withstand the maximum pressure which can obtain in the switch tank, as it is very difficult to prevent secondary explosions.

I would like to hear a little more discussion on the question as to whether the heaviest duty on an oil circuit breaker is at the generating station or at the substation. Mr. Hilliard pointed out that low power factor causes a heavier duty on the breaker, and others maintain that on the substation breaker the recovery voltages being higher, the duty is greater.

On our system the maximum short-circuit current at this time is about 800,000 kv-a. Looking ahead for several years we find that short circuits as heavy as 1,500,000 kv-a. may be expected, and we begin to question whether the system should continue in operation interconnected as one network, or whether it will be necessary to separate the system into two or more parts. We find it desirable to operate as one network in order to secure the best efficiency in plant and line operation. If it is impossible to secure oil circuit breakers which will successfully handle short circuits as high as 1,500,000 kv-a. it will of course be necessary to look for some means of reducing the short-circuit duties.

P. M. Downing: The function of the operating company is to give service—not service when conditions on the system are absolutely right, but service under all conditions. If the manufacturers are unable, with their present equipment, to provide facilities to the operating companies with which they can give service, the operating people, I think, feel that it is up to the manufacturers to provide those facilities, if it is humanly possible to do so, to give that service.

We realize that the operating companies and the manufacturers are up against two problems. First, to provide a switch that will function properly from an electrical standpoint, and the other problem is to provide that switch at a price that the operating companies can afford to pay. Only very recently, within the last two years, the company with which I am associated had occasion to purchase a good many 220,000-volt oil switches. I am not at liberty to quote prices, but the prices of those switches were not low; they were a very important item of expense.

So the manufacturers must get this idea firmly fixed in their minds: That systems cannot be designed around the oil switches. You can't arrange your circuits so as to meet the convenience of the designers or the manufacturers. The public demands service. You must take on any load that comes along, and supply that service. If the present design of switches is inadequate to handle the loads that are carried, then they must be changed, because after all, when you consider that there is a legal and a moral responsibility resting upon the operating companies to give service, it is up to the manufacturers and to the operating companies to provide facilities for giving that service.

E. E. George: I just wanted to express my appreciation of Mr. Jenks' remarks about the need of restoring service promptly. I think it is quite a step in the right direction. The schedules we usually have,—of one minute or two minutes,—for restoring service, ought to be obsolete; they are a relic of the old days when you couldn't get a call through central in less than a minute, when the operators closed all the switches by hand, before we had any dependable relays that we could time accurately. Instead of talking about restoring our service in thirty or sixty or ninety seconds, we ought to speed up to suit the fastest customers, instead of trying to accommodate the slowest ones.

From the standpoint of public relations, probably the residential customer is the most important. He can't protect himself; he has to depend upon the electric company to do it for him. This involves no problem the electric company can't take care of by relay, and at a relatively small expense.

Instead of talking about twenty to eighty seconds before coming back on the line after an interruption, we ought to be able to get back in twenty or thirty cycles.

Mr. P. H. Thomas: Mr. Hilliard, I understood you to say that it was probable that some of the tests made here in the Alabama Power Company on the 44,000-volt breakers were under conditions not as severe as might occur in practise. Could you give some idea what the nature of those conditions are?

Another question: What is the action that actually suppresses the arc—is it the pressure developed, or what is it?

A question to Mr. Jenks: With the study he has made of new ideas, has he something definite to recommend to us better than what we now have in switches?

G. H. Middlemiss: I think there is one paragraph in Mr. Hilliard's paper, of considerable significance. Tests have been made at duty cycles other than standard, in order to determine the relative severity of these supplementary cycles.

There has been a lot of discussion of late as to the standard duty cycle which should be adopted, and I am frankly of the opinion that it is going to be very difficult to secure a duty cycle which is universally acceptable to operating engineers all over the country, due to varying conditions of service and other factors at each particular location.

In our own operation we close some breakers at two-minute intervals, some at one-minute intervals, and others at less. If these breakers are operating at somewhere near their maximum rating of interrupting capacity, we would like to have the manufacturers tell us what multipliers to use in connection with these

breakers, so that we could determine their rating at the duty cycles other than standard.

Another point in connection with contacts is this: We cannot dismantle the breaker every time it functions in accordance with a duty cycle and find out what is wrong with the contacts, or if the contacts are all right. We have other troubles to worry about. We would like to have investigations made, and have the manufacturers give us an idea of how many standard duty cycles the breaker will stand at capacities somewhat near its rating, before we will have to pull the breaker down and redress the contacts, and make other adjustments.

H. P. Sleeper (by letter): Mr. Scholz has dwelt particularly on the method of system connection and the matter of test set-up which was used to procure these tests. I believe that this is a matter of particular interest to us all as it is evident that consistent methods must be used by all companies making such tests in order that the results may be compared on a fair basis. The Duquesne Light Company has begun a series of tests on circuit breakers and we hope to be able to present some interesting data at a later date. In connection with such tests, I would like to mention that we have found it very useful and valuable, as well as interesting, to make a moving-picture record of the performance of breakers on test. We find that the value lies in the fact that the camera catches phenomena of such rapidity as to be entirely lost to the human eye. For instance, there is frequently some question as to where an arc originated. The eye will merely record a flash without detail, but the several pictures recorded on a moving-picture film will show exactly where the phenomena first began. The extent of oil throw and the duration of any visible phenomena can be thus carefully recorded and measured automatically by the moving-picture camera. I believe that the matter of the service testing of such equipment is one that is to be much encouraged among the operating companies, particularly since at the present time it is impossible for the manufacturers to give such equipment service test. It is evident that the solution of such problems is to be one effected by the co-operation of the manufacturers and the operators who are equally interested in the ultimate satisfactory solution of the problem.

J. D. Hilliard: Answering Mr. Thomas' questions as to what really causes arc interruption in an oil circuit breaker, there is no doubt the arc is interrupted by the dielectric strength of the gas in the arc stream and this strength is a function of the temperature and pressure of that stream. In the explosion-chamber breaker we deliberately produce a high pressure and the gas stream is very effectively cooled by the atomized oil injected into the stream as it escapes from the chamber. We also have a high speed produced by the chamber pressure and all of these act to produce a remarkably efficient breaker.

The interrupting capacity of any oil circuit breaker depends upon the quantity of gas generated by the arc within the breaker and the speed of the gas formation.

The rate of gas formation at a given electrode speed varies as the *square* of the time of arcing, not *directly* as the time of arcing, as is generally believed. This can be readily seen if we draw a triangle in which the base represents the duration of the arc in half cycles, the altitude the length of arc in inches, the speed of break being assumed as constant. If we assume that the arc length is the same irrespective of any slight speed variation, then it is evident that the area of the triangle, which represents the gas volume, varies as the square of the half cycles of duration of arc.

If the recovery voltage of the circuit is such as to increase the arc length, then it is probable that the arc will hang after the end of the stroke has been reached and gas will be generated at such a rate as to destroy the breaker. The only safe way is to have the break distance such that the arc is certain to be ruptured by the time the end of the stroke is reached. In oil circuit breakers, where large quantities of gas are formed, the oil is violently projected against the top of the breaker and will lift the breaker from the floor unless it is bolted down.

It is practically impossible to have the gas escape from the tank as fast as generated especially as the projected body of oil plugs the outlet and it is, therefore, necessary to make the tank and top sufficiently strong to stand the gas pressure. The volume of gas is considerably greater than it is generally thought to be, rates of generation exceeding 100 cubic feet per second having been observed in tests. This rapid gas formation greatly stresses the tanks and tops and it is necessary that the construction be made very substantial or disaster will result.

There are various ways of decreasing the quantity of gas generated and the one the General Electric Company has found to be most effective is the explosion chamber. In this breaker we deliberately use high pressures within the chambers to increase the dielectric strength of the gas and to supply a cooling blast of atomized oil which also increases the dielectric strength. The gas is moreover projected vertically downward into the cool body of oil in the outer tank which again acts to cool it and by the time it has risen to the surface of the oil it is at such a temperature that ignition cannot take place from the heat, and moreover a

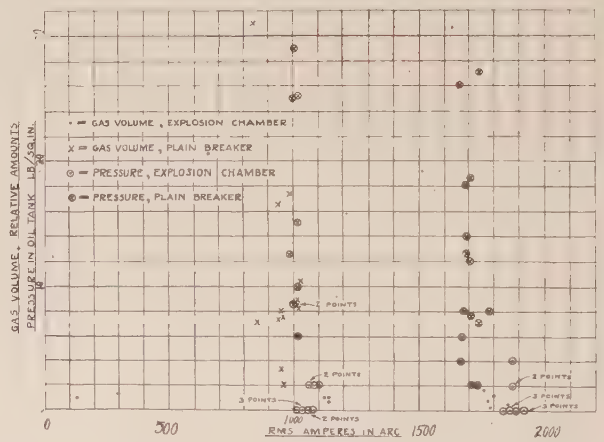

FIG. 2—GAS PRESSURE AND VOLUME IN OIL CIRCUIT BREAKERS WHEN INTERRUPTING ARCS

This chart shows volumes of gas generated and pressures in the oil tank when interrupting arcs of different amperage. It gives a comparison of the explosion-chamber breaker and the plain-break circuit breaker. The gas-formation tests were made at 63.000 volts, identical breakers, mechanism, generators, transformers, and conditions being employed, with the two types of breaks. The gas-volume tests were likewise made with identical conditions for the two types of breaks.

gas mixture containing over 60 per cent. gas cannot be exploded, and at the interrupting rating of the breaker the mixture is always richer than this, so there can be no secondary explosion until diffusion has taken place. We build our newer high-class breakers of such a strength that they will withstand a secondary explosion without damage should one occur.

Answering Mr. Thomas' question as to the conditions at the Alabama Company test, these were all made single-phase at Bessemer, and both single-phase and three-phase at Lock 12, but on the three-phase tests the neutrals were grounded and the short-circuiting breakers were also tied into the ground so that the maximum voltage obtainable across any break was 57 per cent. of line volts.

During all the tests made at Baltimore, I never observed a recovery voltage equivalent to the initial voltage, whereas if the ground had been taken off either the neutral or the short-circuiting breaker, many observations would have been made showing a recovery voltage in excess of line volts. In Schenectady we test with but a single ground so as to obtain the highest possible recovery voltage. It might, of course, be possible to have

surges or resonant conditions which would boost the recovery voltage, but no such evidences were observed in the Baltimore or Alabama Power Company tests.

In reference to the quantity of gas generated in an oil circuit breaker, Fig. 2 herewith shows the relative volumes very clearly. The figure shows the result of tests with an explosion-chamber and a plain-break type of breaker when tested in the same tank under the same load conditions and with the same operating mechanism.

The tests were made in such a way that the measurements of gas volume were correct within two per cent., the gas being measured very carefully after the rate of leakage, which was very small, had been found by test. The method consists in catching the gas and measuring it under standard conditions, *i. e.*, at atmospheric pressure and temperature. The measurements were made upon the fixed gas and any vaporized oil which might be later condensed was not measured. However, the pressure measurements, made in the outer tank of a circuit breaker check the volume measurements and show the remarkable decrease in pressure in the outer tank due to the use of the explosion chamber.

The oil question is one which needs considerable more thought than is given it by the ordinary station man. It is very important that the oil specified by the maker of the breaker be used. We have made a large number of tests upon oil and other liquids and find a wide difference in viscosity, freezing point, quantity of gas formed, carbon precipitation, etc.

The minimum gas formation may be represented by 8, the maximum by 90 when interrupting the same load, and while the pressures are not represented by the same figures, they do correspond in a way. The reason they do not conform closer is undoubtedly due to the presence of the vapor of the liquid which later condenses and consequently is not measured. There is, of course, no such great variation as indicated above in the oils we ordinarily use in the circuit breakers.

J. V. Jenks: Mr. Hilliard questioned my statement that the operator does not know what his requirements are. I am an operator of quite some years' experience, operating one of the largest concentrations of power there is in a system of its kind in the country. I don't know what our breaker requirements are, and I have never met any other operator who did, and on that basis I made the statement.

Mr. Hilliard said that my statement, that no manufacturer had properly equipped himself, is incorrect. I bought from the General Electric Company 51 circuit breakers, guaranteed to break a three-phase arc of 1,000,000 kv-a. I asked the General Electric Company to produce a test to substantiate that guarantee. They said they were not in a position to do it. Mr. Hilliard, himself, admits that his test on his generator which can produce that amount of power might be somewhat different from line conditions; that the resonance or surges of the line might affect it.

We operators don't buy a circuit breaker to be tested and to serve up against a generator—we buy one to be served and serve the public miles away where there are many possibilities of resonance and surges and transformers and other apparatus which which might kick into that breaker.

Mr. Hilliard said there was no advantage in the additional multiple break. The facts are these: That the operator has no facilities for determining many of these theoretic things; we are not equipped to make these tests, and should not be asked to. About the only thing we really have, that means anything, is the "eating of the pudding."

We have on our system General Electric breakers of two breaks, which have a break much more than twice the length of break on the four-break breakers. They never have given, and I don't think it is possible for them to be made to give, the service the four-break breakers do.

Mr. Thomas asked if I had any idea as to what a breaker ought to be. I am going to tell you, in short, the specification which will largely govern the next half million dollars' worth of breakers the West Penn Company buys.

The operating device shall consist of a small motor, which will draw from the supply battery, which is always provided to insure continuity of operation, the minimum current.

The operating mechanism and all breaker units will be rigidly tied together with a steel structure, so that any failure of foundation will not interfere with the operation.

All the multiplying levers will be removed from the breaker proper and put in the operating housing, which will be an all-open-housing, so that all parts possible may be reached without entering the tank. This housing will be large enought to accommodate all necessary relays.

The operating mechanism will be trip-free, leaving as little of the inert mass to be moved by the breaker as possible.

The hand-closing device will be so arranged that a minimum of power will close the switch; also provided with a trip-free mechanism. The trips shall be positive and resetting upon the opening of the breaker. I can point out to you cases where circuit breakers are operating with three trips, three trigger arrangements—one really to hold the contacts, another one to hold the first and another one to hold the second. All of those things are supposed to function and operate properly almost instantaneously. The breaker comes in with a bang, and the triggers are supposed to catch and latch, but they don't do it. We have to adjust to thousandths of an inch, and yet we can't get the results desired. If we get a slight excess pressure on a trigger, the breaker won't trip properly.

So there is no excuse for the tripping mechanism not being made in such a way that it resets itself when it has plenty of time to do it, and then that the mechanism comes up against that locking device and is carried into the closed position.

The tripping device should be so arranged, interconnected with the operating mechanism, that the breaker would be instantly reclosing. Of course, the type of contact we are using now has to stop, but the mechanism does not need to stop. It can be started and continue on, and close the breaker again, re-establishing service as it ought to be re-established at once, not in a minute or two minutes, or some other period. That is necessary for several reasons One of them is that in order to segregate a system, we find from time to time it is necessary, in order to conserve investment, to install air-break apparatus. Air-break apparatus should disconnect faulty pieces in small units where you cannot afford to put a costly circuit breaker, an attendant, and everything else that goes with it. These air breaks will open simultaneously with the oil breaker, but the oil breaker being a little speedier and so relayed, will interrupt the circuit. While the main circuit is interrupted, the air break will open the branch circuit to the part in trouble, and the oil breaker will immediately re-establish service again on the remainder of the system which is not at fault.

The method of transmitting power from the operating mechanism to the various breaker units should be by a torsion shaft, which can be closely fitted and packed to prevent gas passing from one unit to another and to prevent the entrance of moisture.

The series transformer should be sectional-wound, making it impossible to get a number of different ratios. It should be confined in a part of the supporting casting which normally supports a bushing; be sealed absolutely from the gas in arc chambers; removable integral with the bushing and connected on its low-voltage side by weather-proof conduits entirely outside of the breaker. The bushings, themselves, should be very liberally designed and of a very rigid nature, so that great magnetic stresses will not damage them.

The tank should be top-attached, to eliminate the possibilities of voids at the top which occur when tanks are supported from the bottom. Switch tanks do bulge and bolts do stretch, and when a tank bulges or a bolt stretches, if supported from the

bottom, it leaves an opening around the top of the tank. The top of the tank should be sealed by a gasket on the order of a pump-sucker, which would close tighter with pressure, instead of opening on a slight movement of the tank at the top. The tank should have a bump bottom with an internally packed drain at the lowest possible point. It should be equipped with permanent lifting facilities in the case of those tanks which are lowered for inspection.

All openings to the tank or top should depend upon gaskets only for preventing capillary attraction of moisture. The idea of manufacturers building a breaker with a top of such form that the water remains on it and is prevented from going into the breaker by only a gasket, is something that the operator ought to insist on having corrected.

Linings should be of fire-resisting material. Particularly an inner lining should be designed to withstand arcs rather than have any particular insulating value. The lining next to the tank should have a high dielectric strength. Liners should be supported in a manner which would keep them from the moist oil in the bottom of the breaker, where they absorb the moisture, and which reduces their dielectric strength.

At least six, magnetically directed, barriered contacts should be provided, to assure series breaks which will speed up the break, which will keep the gases segregated, so that they can be cooled and conducted to the air chamber in the top of the breaker without danger of ignition from over-temperature.

The top of the breaker should be provided with a suitable baffle arrangement, which will absolutely prevent oil from being discharged from the vent. The vent should be self-hermetically sealed, and the breaker should be provided with a dependable breather. The manufacturers have for years done all within their power to keep moisture out of a transformer, which in reality can stand more moisture than a breaker. Because of the temperature in the transformer and the viscosity of the oil generally being kpet at fairly constant value, the moisture does get to the bottom of the tank without doing much damage. The oil is not agitated in the transformer as it is in the breaker, where the moisture is stirred up. Yet, they build breakers with unprotected vents, so arranged that a very light snow will build snow all round them and then the breakers breathe through snow—and we do know that breakers breathe. It seems to me that instead of trying to keep the moisture out of the breaker and make the breaker the most dependable thing, we have lost sight of some very essential things which we have found in other electrical apparatus.

Such a breaker should, without throwing oil, still be fit for service at its rating after opening at least five times consecutively, under any system condition, irrespective of power factor, grounds or number of phases. If we get such a breaker—and I believe it can be developed at not much greater cost than what we are paying for the present-day breaker—I think that our breaker problem will be largely solved.

LIGHTING FOR WILD WEST RODEO

Recently, when the United States Championship Cowboy Rodeo Company gave a series of shows in the East, night performances were given under perfect lighting conditions.

The outdoor illumination, according to "Lighting and Fixtures" (New York), embraced a performing space, 600 feet by 125 feet with 72 500-watt lamps placed in suitable outdoor lighting fixtures. These fixtures were suspended twenty-five feet above the track on quarter inch galvanized iron rope cables. Two-inch galvanized pipe was used for poles, with a specially constructed top fitting for fastening the guys.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

IT'S SMALL, BUT IT DOES ITS JOB

Six hundred dollars a kilowatt-hour! Sounds like the cost of energy at the North Pole, yet that is the cost of the energy consumed by a vestpocket flashlight. This seems rather extravagant when compared with the central station rate for this same kilowatt hour. It is not excessive, however, because the tiny flashlight lamp uses such a small fraction of a kilowatt, so small in fact that the lamp will burn for 2000 hours on a single kilowatt-hour of energy. And as for results, the comfort, convenience and safety of a ready flashlight are worth much more than their actual cost.

Fortunately, that marvelous instrument of vision,

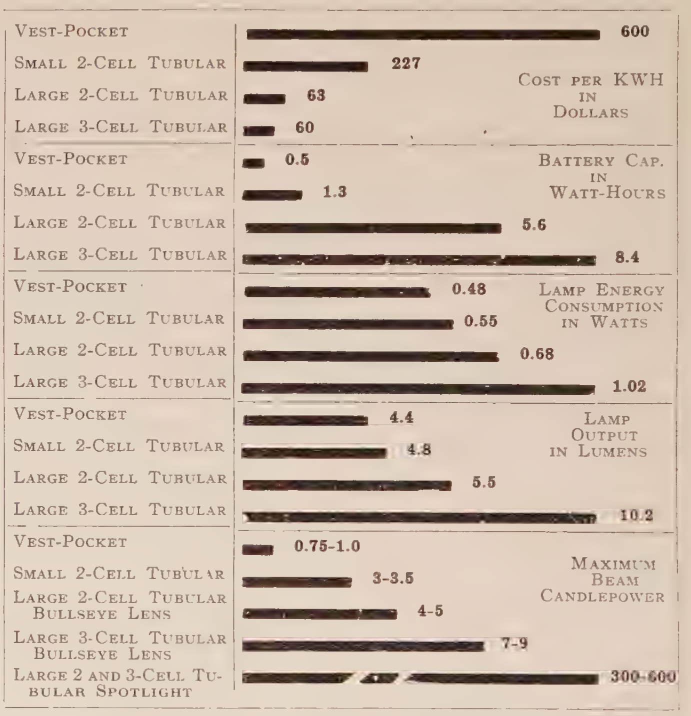

Fig. 5—Comparison of Common Types of Flashlights with Reference to Cost per kw-hr., Battery Capacity, Lamp Watts, Lumen Output and Candlepower

the eye, functions through a wide range of intensities and is as alert to see the small area revealed at midnight in the momentary flash of the tiniest flashlight as it is to encompass the horizon under 10,000 foot-candles of sunlight at high noon. So, for short periods, the light from a small flashlight lamp which takes less than one watt of power, fills the requirements for emergency or intermittent lighting at a cost low in comparison with the value of the special service rendered.

Flashlight lamps have two important design features:

First, they take a low current so that maximum battery life will result.

Second, they operate at a high efficiency so that a maximum candlepower will be received from the small amount of energy available.

For some uses, only a very compact flashlight is

desired for convenience in carrying. The standard for this service is the 2-cell vest-pocket flashlight. The lamp used in this type requires only one half of a watt and, with the open reflector used this unit gives a broad beam diverging over 150 degrees; this beam is of sufficient intensity, however, for reading addresses at close range, looking for lost articles indoors, and the like. Although the battery life is only one hour while the lamp is burning, this really corresponds in most cases to several months of intermittent service.

The batteries of the small 2-cell tubular unit have a capacity of over two and one-half times the vest-pocket type, and the energy cost per kilowatt-hour is reduced to about two hundred and thirty dollars. With special reflectors and a bulls-eye lens the light from the lamp in this unit is confined to a 70-degree beam, the higher candlepower being better adapted for general service. The lamp takes 0.55 watt.

For all-around service, the larger two and three cell standard tubular types using standard unit cells of 1 ⅜ inch diameter, offer the greatest utility. Instead of the six hundred dollar kilowatt energy cost with the vest-pocket flashlight, these units supply a kilowatt hour for only sixty dollars; the larger capacity battery gives the more efficient service. For the majority of indoor and outdoor uses, a 50 to 70-degree beam meets the requirements. This is produced with a silvered or enameled reflector, bulls-eye lens, and lamp. The lamp used with the 2-cell flashlight of this type consumes 0.68 watt and gives an average maximum beam of about four or five candlepower for a seven to eight hour intermittent burning period. In the 3-cell tubular flashlight the lamp takes 1.0 watt and gives seven to nine candlepower in the main beam.

When it is desired to illuminate surfaces of objects over 15 or 20 feet away with only about 0.8 lamp candlepower available from the three cell flashlight lamp, the light must be confined to a narrow beam. This is done by using a very concentrated filament lamp and a parabolic reflector. The lamp is focused in the reflector by screwing either the lens end or the base cap, depending on the make. The reflector of such a focusing spotlight is protected by a flat or curved cover glass of uniform thickness which has little or no bending action and is used merely to keep out dirt and moisture. Beams of several hundred candlepower are obtained, suitable for reading house numbers and road signs, for boating, meter reading, for watchmen and police—for all services where illumination is needed for greater distances. These focusing flashlights are made in both the two and three cell types, for the standard 1 ⅜ inch diameter batteries used in the bullseye lens units. One extra lamp, sometimes two, is carried in the cap at the end of the battery—a very practical feature for the user which could be incorporated to advantage in the other types of flashlight cases.

The accompanying chart shows a comparison of some of the technical features of the common types of flashlights described above.—*Light*, January 1925.

COLOR SHADOW LIGHTING

Hardly a city exists which does not have a prominent monument or monumental building. With a few scattered exceptions, all are obliterated by nightfall. During the day their beauty may be marred by the surroundings; at night they may be set free from their environment and made to stand nobly out as an inspiration to their beholders. If the building is a commercial one, as for example are the Woolworth tower of New York and the Wrigley tower of Chicago, the publicity gained by courageous flood-lighting is beyond calculation.

Color shadow lighting, when applied to similar examples of our modern architecture, provides a means for enhancing the beauty of such architectural accomplishments to an even greater degree than has been made possible with the aid of the large banks of flood-lamps as are used for the night illumination of the two structures mentioned above. Color in itself, is attractive and when intelligently used to create brilliant splashes of color which harmonize with the architectural design of the building, some truly magnificient effects can be secured.

The use of color permits variegating the appearance of a building at will to a much greater extent than is possible with clear flux. Likewise, with colored light, the amount and kind of color is under perfect control and the amount of color decoration can be modified or eliminated at any time, if so desired. It lends itself particularly well to the lighting of such structures as are stepped back from the building line progressively at certain elevations, since such architecture creates pockets and offsets that can be strongly splashed from points of vantage on the building itself. This permits the pillars and other outstanding features of a building, to be bathed with white light, thus sharply contrasting them against a background of colored shadows.

It is only necessary to recall such awe-inspiring applications of colored lighting as were witnessed at the San Francisco Exposition, to realize the many possibilities which may be uncovered by the resourceful designer.

Such applications will also create an additional power demand because the projected area of buildings suitable for such exterior illumination ordinarily runs from 20,000 sq. ft. to 100,000 sq. ft., requiring a connected lighting load of from 100 to 1000 kw. The burning hours run considerably beyond the peak and would average more than 1800 per year. In other words there is a potential requirement of 180,000 kw-hr. and upwards per building per year.—Abstracted from the *Electrical World* of Nov. 22, 1924.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Midwinter Convention Plans Completed

Arrangements are being completed for the Midwinter Convention which will be held in New York City, February 9th to 12th. Everything points to a most successful meeting. The entertainment committee has planned functions which will give much pleasure to those attending; a large number of inspection trips have been arranged and these are listed in following paragraphs. The technical papers are of excellent character. They cover such subjects as electrical machinery, instruments and measurements, electrophysics, communication, transmission, cables, storage batteries and statistical forecasting.

Among the social functions there will be a smoker on Monday evening and a dinner-dance on Thursday evening, Lincoln's birthday. Both of these events will be at the Hotel Astor. On Wednesday evening there will be the presentation of the Edison Medal and an address on airship development by Major-General M. L. Patrick.

A complete program was published in the January issue of the JOURNAL, page 83.

The general committee in charge of local arrangements is as follows: L. F. Morehouse, Chairman, H. H. Barnes, Jr., W. S. Gorsuch, E. B. Meyer (chairman of Sessions Committee), L. W. W. Morrow, H. S. Sheppard (chairman of Feature Meeting Committee) and R. H. Tapscott (chairman of Finance Committee). The Entertainment Committee consists of H. H. Barnes, Jr., chairman, F. M. Feiker (smoker), H. A. Kidder (dinner-dance) and J. C. Parker (excursions).

Inspection Trips

A number of interesting inspection trips have been planned. The following trips have been definitely scheduled for Wednesday, February 11th:

BELL TELEPHONE LABORATORIES, INC.
(RESEARCH LABORATORIES OF AMERICAN TELEPHONE & TELEGRAPH CO. AND WESTERN ELECTRIC CO.)

Features of interest: Carrier-current telephone apparatus for power lines, remote-control systems for power substations, artificial larynx and demonstrations in acoustics, chemical laboratory, telephone transmission, special research laboratories, apparatus development laboratories, machine-switching systems and historical exhibits.

HUDSON AVENUE GENERATING STATION,
BROOKLYN EDISON COMPANY, INC.

Features of interest: Three 62,500-kv-a. single-shaft turbo generators, one with enclosed ventilating system, 27,000-volt vertical isolated-phase switching, disconnecting-type oil circuit breakers with electrical raising and lowering mechanism, permanently installed grounding and testing switches and bus with kenotron testing equipment, step-up auto-transformers with cables sweated to transformer potheads and radiators banked on headers, unit-type steel switchboard cubicles, truck-type station auxiliary circuit breakers and Ward-Leonard controlled stoker auxiliaries and coal tower.

The following trips may be taken by individuals or groups:

Automatic Substations. New York Edison Co., three 1500-kw. 250-volt three-wire motor-generator sets with remote supervisory control; New York Central Railroad, two 2000-kw. 660-volt motor generators with load-limiting features and high-speed d-c. circuit breakers; Public Service Co. of New Jersey, two automatic railway substations in Newark, one in Bloomfield and noise-proof automatic station Newark.

Frequency Changer. United Electric Light & Power Co., Hell Gate Station, 35,000-kw. synchronous induction set with 60-cycle rotor and connected to 25-cycle source. Set equipped with silencer.

Synchronous Converters. New York Edison Co., three 4200-kw. totally enclosed synchronous three-wire Edison converters. Two are booster type, one has field control.

Supervisory Control. Hell Gate Station, United Electric Light & Power Co., distribution-type remote circuit-breaker-operation indicator; Bayside Substation, New York and Queens Electric Light & Power Co., remote circuit-breaker control and indicator.

Large Turbo Generator. Hell Gate Station, United Electric Light & Power Co., 62,500-kv-a. cross-compound turbine.

Truck-Type Substation. Kings Highway Substation, Brooklyn Edison Co., 20,000-kw. substation with truck-type switching, transformers with cables sweated to potheads.

Elevators. Standard Oil Company Building, multi-voltage full automatic control; Equitable Life Assurance Bldg., Ward-Leonard control.

Machine Telephone Switching. New York Telephone Co., Thirty-Sixth St., large machine-switching telephone exchange (open daily, noon till 2 p. m., during Convention).

Radio Broadcasting Station. Station WEAF. (open daily from 4 to 6 o'clock during Convention).

Electric Ship Propulsion. Three municipal ferries equipped with turbo generators and induction motors.

Industrial Installations of Electric Drive. Artic Hygia Ice Plant, three 750-h. p., two 450-h. p. and three 150-h.p. synchronous motors direct connected to compressors; Botany Worsted Textile Co., modern textile installation; Lowe Paper Co., small modern paper mills; New York Belting and Packing Co., 10,000 h.p., of motors installed; Driver-Harris Co., steel-rolling mill; Stewart Hartshorn Co., modern electric steel furnace; Raritan Copper Co., modern electrified copper plant; R. H. Macy & Co., large battery-charging and ventilating plant.

Lamp Manufacture. Edison Lamp Works of General Electric Co., with specially prepared exhibition; Westinghouse Lamp Co.

Electric Ovens and Furnaces. Durant Motors, Klaxon Co., General Electric Co., Steinway Piano Co.

Electric Welding. Metropolitan Engineering and Device Corp., Repair Shops of 3rd Avenue Railway Co.

Boilers and Stokers. Sherman Creek Station, United Electric Light & Power Co., automatic boiler control (Smoot type) on 44 650-h.p. boilers, pulverized-fuel installation, six 628-h.p. boilers, these boilers equipped with finned water tupes in side walls; Hell Gate Station, United Electric Light & Power Co., record-efficiency stoker-fired boilers with finned water tubes in side walls; Fifty-Ninth Street Station, Interborough Rapid Transit Co., longest stokers built (37 tuyeres), experimental coke-recovery plant in connection with ash-disposal system; Hotel Commodore, N. Y. Central Railroad, two 2000-h. p. boilers installed 85 ft. below ground.

Diesel Engine, Brooklyn Navy Yard. A Diesel-engine outfit will be on test and arrangements have been made to have Naval Officers show the equipment to visitors.

Power Plants and Industrial Applications on Spring Convention Program

A program of varied interest is being planned for the Spring Convention which will be held in St. Louis, April 13 to 17. As St. Louis is a center of power generation and industrial development a number of the papers will deal with these two phases of engineering. There will be papers on several new power plants and automatic stations. Sessions will be held, respectively, on mining and marine applications and papers are being planned on the uses of electricity in manufacturing rubber, cement, shoes, glass and paper. Several papers on electrical machinery, electromagnetism and electrophysics are contemplated and there will be one session devoted to communication topics.

Among the features of the meeting it is hoped to have addresses by Mr. Louis H. Egan, President, Union Electric Light and Power Company, and Dr. F. B. Jewett, Vice-President, Western Electric Company.

There will be inspection trips to many of the engineering developments in the neighborhood of St. Louis, including power plants and substations and many kinds of manufacturing establishments which abound in this territory.

A number of social and sports features are being arranged to add to the pleasure of those who attend.

A large and well organized local committee is working diligently to make the meeting a successful one and all who have an opportunity to be present are assured of an enjoyable and profitable occasion.

The general committee of arrangements for this convention as appointed by President Osgood, consists of Messrs. B. D. Hull (Chairman), Edward Bennett, H. E. Bussey, J. M. Chandlee, H. W. Eales, J. Harrison, Chris. H. Kraft, L. W. W. Morrow, C. P. Potter, W. L. Rose, Herbert S. Sands. Subcommittees have been appointed, the chairmen of which are as follows: Entertainment, W. L. Rose, Finance, G. A. Waters; Publicity, C. L. Matthews; Registration and Hotel, J. M. Chandlee; Special Feature, C. H. Kraft; Technical Inspection, C. C. Robinson; Technical Meetings, C. P. Potter, and Transportation, J. L. Buchanan.

Future Section Meetings

Baltimore

"The Klydonograph," by Dr. J. F. Peters, Westinghouse Electric & Mfg. Co. February 20, 8:15 P. M., Johns Hopkins University.

"The Pallophotophone, by Dr. C. A. Hoxie, General Electric Co. March 20, 8:15 P. M., Johns Hopkins University.

Cincinnati

"The Failure of Dielectrics," by Wm. A. Del Mar, Habirshaw Electric Cable Co., February 12.

Erie

"Manufacture of Railway Motors," by Don F. Smith, General Electric Co., February 17.

"Patents and Inventions," by A. A. Buck, General Electric Co. March 17.

Fort Wayne

"Supervisory System for Automatic Stations," by Chester Lichtenberg, General Electric Co. This will be illustrated by movies. To be held at G. E. Club Rooms, Building16-2, 8:00 P. M. February 19.

Talk relative to Traction Work by R. M. Feustal, President Indiana Service Corporation. Moving Pictures. To be held at G. E. Club Rooms, Building 16-2, 8:00 P. M. March 19.

St. Louis

"A Resume of the Past Year's Achievements in Electrical Engineering." February 25.

Electrical Transmission of Pictures. March 25.

Seattle

"Recent Development in Propulsion," by F. K. Kirsten. February 18.

"Broadcasting by Radio and Long Lines," by J. W. Greig and J. R. Tolmie. March 18.

Springfield

"The Magnetic and Electric Survey of the Oceans on the Non-Magnetic Yacht "Carnegie," by Captain J. P. Ault, Carnegie Institute. This lecture will be illustrated by slides, and a film, which will show the huge icebergs encountered during the cruise around the South Pole. February 9, Olivet Community House.

Vancouver

"Alouette Power Developments," by E. E. Carpenter. February 6.

"Main-Line Railway Electrification," by R. Beeuwkes. March 6.

Regional Meeting in Washington is Most Enjoyable

Washington, D. C., was the scene of a very successful regional meeting which was held on January 23 and 24 under the auspices of the Middle Eastern District of the Institute. The technical features consisted of six papers or addresses by prominent engineers. A delightful dinner was held at the Washington Hotel at which Herbert Hoover and Brigadier-General William Mitchell made addresses. The inspection trips were of great interest and in all, the gathering was a splendid one.

Herbert Hoover Urges Definite Participation in Public Affairs

One of the most valuable and enjoyable features of the meeting was the address by the Secretary of Commerce, Herbert Hoover. Mr. Hoover urged practical participation by engineers in public affairs. He suggested that councils of engineers be formed in different localities for the definite purpose of discussing public affairs and issuing statements of their thoughts on matters which by training they are fitted to discuss. For the good of the country he advised a combination of the qualitative thought of the engineer with the quantitative thought of the economists.

Brigadier-General William Mitchell, Assistant Chief of Air Service, U. S. Army, told of the great developments which have been made in aerial navigation for civil, commercial and military purposes. He showed many interesting slides and motion pictures, those depicting the tests on the sinking of ships by means of air bombs being of particular interest.

Three scheduled trips of inspection drew large attendances, and numerous other trips were taken by small groups and in-

dividuals. The three features trips were (1) a motor trip to Mt. Vernon, Alexandria, Arlington, the Lincoln Memorial and other points, (2) a trip to the Bennings Plant of the Potomac Electric Power Company and to the Bureau of Standards, and (3) a trip to the museums and art galleries, the Library of Congress, the U. S. Capitol, etc.

Altogether the arrangements of the local committee in Washington were excellently planned and carried out. This committee and the Executive Committee of the District deserve much commendation for the organization and conduct of this very successful meeting.

The Technical Sessions

The first session opened Friday morning with a paper *The Artificial Representation of Power Systems by Miniature Networks*, by H. H. Spencer and H. L. Hazen. This paper described a miniature single-phase setup which may be employed to duplicate conditions on practical alternating-current networks. Loads and lines are represented by lumped resistances, reactances and inductances. The paper is published on page 24 of the January issue of the JOURNAL.

Dr. Joseph Slepian then presented *The Theory of the Autovalve Lightning Arrester.* He showed the advantages of employing a valve action in an arrester describing in particular the action of a very thin film of air (less than 0.001 cm.). He showed the advantage of placing a mica spacer between the plates and in the gap, also the necessity for employing plates of high electrical resistance to prevent the concentration of current due to irregularities of the surfaces or non-homogeneity of the plates. In discussing the paper, K. B. McEachron mentioned that the high resistance is useful also for the purpose of stabilizing the arrester. He also asked the question: As the arrester gaps are in series with the line gap, how and to what degree do the small arrester gaps become charged in the very short time necessary for proper protection of equipment? Answering this question Dr. Slepian stated that on rapidly applied potential the line gap takes most of the voltage as the several small gaps have a higher condenser capacity than the line gap. After arc-over across the line gap, the series of small gaps of course is subjected to practically the full voltage. The entire arrester he asserted acts very quickly at the break-down voltage. A. L. Atherton stated that, depending on the type of autovalve arrester, the discharge will start at about 75 per cent over the gap setting (on the small arresters) to only a little higher voltage than the gap setting (on the larger arresters). Dr. Slepian pointed out that the valve type of arrester will not stand a high discharge for a long period of time. Consequently if dynamic overvoltage is allowed on a line the arrester must be chosen with regard to this dynamic voltage. He stated that a resistance shunting part of the arrester would not be desirable. Such a resistance would necessarily be high in order to allow the line gap to break the power current and in this case it would be of no assistance in connection with surge voltages. Among others discussing this paper were W. L. Lee, H. B. Smith and M. J. Idail.

On Friday afternoon E. C. Crittenden presented a paper by A. E. Kennelly entitled *The Thermal Time Constants of Electrical Machines.* This paper proposes a new constant to be used in rating electrical apparatus. Basically the constant is the length of time during which a certain rated load will produce a certain temperature rise. This paper is published on page 142 of this issue of the JOURNAL. J. C. Parker pointed out how difficult it would be to obtain a constant which could be used accurately with complicated machinery such as a large turbogenerator. The effects of radiation and convection and of varying power factor and field excitation he stated would make such a constant difficult to determine and apply. W. B. Kouwenhoven stated that in some tests he had conducted on transformers not larger than 10 kv-a. in size he had employed very satisfactorily an exponential curve as suggested by Dr. Kennelly. On more complicated apparatus such a curve was tried but would not give trustworthy results. W. L. Lee mentioned that the use of a "binary" constant as suggested in the paper greatly simplifies calculations wherever the plan outlined can be applied. He pointed out that the thermal effect of very quick peaks has not been covered and that there is a field for study on this line. L. W. W. Morrow pointed out the difficulty of having such a rating constant understood by many purchasers of equipment. It might be applied satisfactorily to large machines over which there is present technical supervision though temperature indicators are usually installed on such machines to serve the same purpose. Others contributing discussion were Frank Wenner and D. M. Simons.

The next speaker was J. B. Whitehead who talked on the work of the Committee on Electrical Insulation. He told how the work had been allotted to six subcommittees which are studying all the present literature on the subject of insulation and will later outline the particular problems which need further investigation. He pointed out the difficulties of getting qualified members to devote the requisite time to the work and emphasized the need of financial support. As one phase of the committee's activity he mentioned the study of dielectric absorption and pointed out the present knowledge of this subject and the need for further study. T. J. McKavanaugh stated that in connection with ocean-cable work it appeared that pressure is one factor affecting dielectric absorption. H. B. Smith enumerated the four types of circuits which concern electrical equipment, namely, the electric, the magnetic, the dielectric and the thermal. The first two have been most extensively studied in the last few years, while the solution of the second two is now the next step in the development.

On Saturday morning a paper *The Economics of Power Factor Correction* was presented by L. W. W. Morrow. He pointed out that technically the problem of raising power factor has been solved and now the problem is purely a business problem. Mr. Morrow indicated conditions under which correction might be economical and outlined practical methods of raising power factor. (This paper is published on page 150 of this issue of the JOURNAL.) In discussing the paper M. E. Skinner mentioned the difficulties of showing central-station customers the advisability of raising power factor. He stated that the complexity of some of the power-factor clauses in rate schedules is disgraceful. He favors the use of meters in the customers' premises, if they can be used without too great an expense. H. R. Woodrow agreed with the author that the correction should be done on the customers' premises. His company does not have a power-factor clause in its rate schedule but secures very good results by watching the new installations closely, consulting freely with the customers and agreeing on the use of high-power-factor equipment by individual contract. The customers are usually found entirely ready to coöperate. At peak loads his company has a power factor of about 87 per cent. H. M. Hitchcock said there is often too much hesitancy in asking customers for cooperation as they usually agree willingly when they understand the facts. He thought that Mr. Morrow had underestimated the cost to the generating system of poor power factor, contending that it does decrease the margin of operating safety.

J. F. Gaskill said that over 27,000 kv-a. of corrective equipment has been installed by customers in Philadelphia. This has been accomplished mainly by individual consultation with each customer. No complaints of any importance had resulted. The job he stated is mostly a commercial one. The metering is difficult and reactive kv-a. meters have been tried and abandoned. The periodic test is now satisfactorily employed with a demand form of rate. Overmotoring, he thought, in many cases is done for safety and for securing adequate starting torque and often it cannot be eliminated. F. L. Hunt agreed that the entire problem is now a commerical one. He thought however that the charge of $6 per each kv-a. of power-plant equipment released by raising power factor is too low a charge. L. H. Rittenhouse

emphasized the necessity for a simple rate. He also remarked on the difficulty of getting customers to make any expenditure of money for correcting power factor when they think that the same amount spent for other purposes, such as advertising for instance, will give them larger returns.

In answering some of the questions raised, Mr. Morrow explained the reasons for setting a value of $6 per kv-a. on equipment released by raising power factor. One of the main reasons is that generating equipment for 80 per cent power factor, for instance, will cost only slightly more than equipment of the kilowatt capacity rated for 90 per cent power factor. As regards overmotoring he thought that the customer is often right, on account of the variation in loads and production and the shifting of machines found necessary in many industrial establishments. Good service to the customer he pointed out is the first requisite. The improvement of power factor may help to maintain good service but the presentation of a rate clause should be only the final step. He mentioned that in some companies where rate clauses have been in effect a study showed that the receipts from penalties were far less than the bonuses paid. R. H. Silbert and L. F. Deming also contributed to the discussions.

H. R. Woodrow then presented a paper on *The Use of Frequency Converters for Interconnection of Systems.* He told of the 35,000-kv-a. synchronous-synchronous frequency changer which ties together the 60-cycle and the 25-cycle systems of the Brooklyn Edison Company. This machine allows the base load of the company to be carried on the new 60-cycle generating equipment which is the most efficient generating equipment of the company. It also allows a pooling of the entire reserve capacity for use on either the 60-cycle or the 25-cycle side. As a result of this tie-in one less unit is now kept on the bus at all times. The number of lightly loaded units at various periods has also been reduced.

M. E. Skinner, in discussing the paper asked how this type of machine would behave under heavy fluctuations of load. He had in mind the question of tying together the generating systems of a steel mill and of a central-station company. A. S. Loiseaux stated that his company was also contemplating the use of large frequency changers for tying together two systems of different frequencies. The advantage of securing additional capacity for one system or the other by this means was that it would cost only 20 per cent of the price of generating equipment for the same purpose. H. H. Spencer stated that the 100 per cent overload allowed for the frequency changer is well within safe limits as such a swing of load will usually be impossible. Load cannot usually come on to synchronous apparatus so fast, and the worst possible load in average cases which will be thrown on generating equipment when other generators are tripped off the circuit, is probably 50 per cent of the rating of the equipment which dropped off. He thought that Scherbius control would give even greater flexibility in case of sudden increase of load. Mr. Woodrow pointed out that the factor of 2 had prevented trouble and he would rather not lower it especially as unforeseen conditions might arise such as the swinging action of a governor which might increase the instantaneous load.

Answering the question in regard to supplying a steel-mill load through such a frequency charger, Mr. Woodrow cited the fact that his machine carries a railway system which has load fluctuations of 200 per cent amplitude and that the operation is entirely satisfactory. Mr. Woodrow pointed out that on short circuit the transfer of power from one system to the other is small with the synchronous-synchronous frequency changer. This type of set transfers only power (kilowatts) from one system to the other and not kilovolt-amperes. Mr. Woodrow further mentioned that the two units of the set are connected together with a rigid bolted shaft, though when a second set is added this will have an armature-shifting device. Others contributing to this discussion were F. R. Ford and W. L. Lee.

The Institute Election

The nomination ballots for officers of the Institute will be mailed to the entire membership during the first week in February.

Four advance nominations for the office of President were made by petition, and three of the candidates so nominated have notified the Secretary of the Institute of their withdrawal in favor of Dr. M. I. Pupin, as indicated in the following quotations from these letters:

Mr. Charles E. Skinner:

"I have learned that Doctor M. I. Pupin has been nominated for the Presidency of the American Institute of Electrical Engineers, and, this being the case, it gives me pleasure to withdraw my name in favor of Doctor Pupin.

"I very keenly appreciate the action of my friends who have been good enough to put my name in nomination; but I feel quite sure that they will gladly give their whole-hearted support to a candidate of Doctor Pupin's eminence in the profession and one who is so vitally interested in the affairs of the Institute, as well as being possessed of such rare personal charm."

Mr. R. F. Schuchardt:

"Some of my friends have been kind enough to place my name in nomination as a candidate for President of the Institute this year.

"In view of the nomination of Professor Michael Pupin for this honor and his acceptance of the nomination, of which I learned subsequently, I am very happy indeed to withdraw. I believe the Institute would be distinctly honored in having a man of Professor Pupin's attainments and standing in the scientific world as its President."

Mr. L. T. Robinson:

"Referring to Institute By-laws Section 19, please withdraw my name from the printed list of candidates for nomination for President of the Institute.

"I am taking this action because I have learned that Dr. Michael I. Pupin has been suggested for the office of President and that he has agreed to stand as a candidate. In view of Dr. Pupin's great distinction in the science of electricity, I appreciate this opportunity to withdraw in his favor and to support him for the presidency."

A. I. E. E. Directors' Meeting

A meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Wednesday, January 21 1925.

There were present: President Farley Osgood, Newark, N. J.—Vice-Presidents S. E. M. Henderson, Toronto; William F. James, Philadelphia; L. F. Morehouse, New York; Harold B. Smith Worcester—Managers A. G. Pierce, Pittsburgh; Harlan A. Pratt Hoboken, N. J.; H. M. Hobart, Schenectady; G. L. Knight, Brooklyn N. Y.; W. M. McConahey, Pittsburgh; H. P. Charlesworth, New York; John B. Whitehead Baltimore—Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

A report was presented of a meeting of the Board of Examiners held January 12; and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 279 Students were ordered enrolled; 198 applicants were elected to the grade of Associate; 6 applicants were elected to the grade of Member.

Approval by the Finance Committee of monthly bills amounting to $25,432.32 was ratified.

Upon the recommendation of the Sections Committee, the Board authorized the organization of a Nebraska Section of the Institute, to include Pottawattamie County, Iowa, and the entire state of Nebraska, and granted a request of the Mexico Section for an extension of territory to include all members in Mexico.

Authority was given for the establishment of a Student Branch of the Institute at the South Dakota State School of Mines.

The Board approved as A. I. E. E. Standards, the following three sections of Institute Standards submitted by the Standards Committee:

Standards for Electric Arc Welding Apparatus—No. 38

Standards for Synchronous Converters (to become effective six months after date of official adoption)—No. 8

Standards for Instrument Transformers—No. 14

Consideration was given to the proposed World's Congress of Engineers, Philadelphia, 1926; and upon the recommendation of the Joint Conference Committee (consisting of the Presidents and Secretaries of the Founder Societies), the Board voted that the Institute withdraw from participation in this proposed congress.

A report was received from the President of the U. S. National Committee of the International Commission on Illumination, and copies of the report were ordered sent to the members of the Board.

Proposed amendments to the constitution, formulated by the Constitutional Revision Committee, which was appointed by the Board at its December meeting to formulate amendments in accordance with various revisions that had been suggested, were considered and adopted for submission to the membership for vote.

The following resolution was adopted:

Whereas, the Constitution provides in Section 40 that "the Secretary shall be the executive officer of the Institute," and as it is desirable that he shall have a title to indicate this fact,

Resolved: That the Secretary be given the additional title of Executive Manager, to be used on suitable occasions within his discretion.

Reference to other matters discussed may be found in this and future issues of the Journal under suitable headings.

Annual Meeting of the Mining Engineers

The American Institute of Mining and Metallurgical Engineers will hold their annual meeting February 16-19, 1925 at the Engineering Societies Building, 29 West 39th Street, New York, N. Y.

An emphasized subject to be discussed at this meeting will be placed under the heading "Corrosion" and it is expected that the technical meetings held for the discussion of this important matter will result in some valuable debate. It has been remarked that "Corrosion" is getting into the class of the crossword puzzle, so popular has the subject become, but the Mining Engineers express a hope that, with development, it will maintain the dignity of the word "research," rather than lapsing into the same category of its much overworked brother "efficiency."

Corrosion in metals, it is declared, is synonymous with waste and decay. "The study of Metallurgy—the Making of Metals" has only limited appeal, to those connected with manufacturing interests, but "the study of Corrosion—the Unmaking of Metals" has an interest for all who use metals. Waste of natural resources is a matter of considerable research at the present time and it is estimated that millions of dollars annually go to waste because of the corrosion of metals. It is because of its obvious importance that the Institute of Metals Division of the A. I. M. E. has made "Corrosion" one of the chief subjects for the February program. Dr. Carl Benedicks, Director of the Metallographic Institute, Stockholm, will be one of the speakers.

John Fritz Gold Medal Awarded to John F. Stevens

The twenty-first award of the John Fritz Gold Medal was made January 16 to JOHN FRANK STEVENS, of New York City, for great achievements as a Civil Engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern Railway.

This Medal was established in 1902 in honor of John Fritz, one of the great pioneers in the American iron and steel industry. It is awarded annually for notable scientific or industrial achievement and is the highest honor bestowed by the engineering profession in this country.

The award was made by a board of sixteen representatives of the American Societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers, having a total membership of 53,000.

Mr. Stevens is one of the most widely known and highly esteemed American civil engineers. His name is associated especially with the Panama Canal, the American Railway Mission to Russia, and construction and operation of important railway systems in the United States. He is an Honorary Member of the American Society of Civil Engineers, and of the Association of Chinese and American Engineers, Pekin. He is also a member of other American and foreign engineering societies.

Mr. Stevens, as Head of the American Railway Mission to Russia, 1917-1918, rendered heroic service toward the success of the allied nations in the great war. He was also Director of a corps of railway experts in Manchuria. From 1919 to 1923 he was President of the Inter-Allied Technical Board supervising the Siberian Railways, bringing a notable measure of order into the chaos of the Siberian railway situation. While holding this office, with headquarters at Harbin, Manchuria, he supervised the technical and economic operation of the Siberian and Chinese Eastern Railway.

Mr. Stevens was Chief Engineer of the Panama Canal from 1905 to 1907 and in 1907 acted as Director of the Isthmian Canal Commission. His masterful organization of personnel of the Canal forces, and especially of the transportation system, contributed mightily to the effective construction work on the Canal under his successor, General Goethals.

At various times in earlier periods of his life, Mr. Stevens was Chief Engineer, Vice-President, or Manager, of the Great Northern Railway, Chicago, Rock Island and Pacific Railway, New York, New Haven & Hartford Railroad, and President, successively, of the Spokane, Portland & Seattle Railway and the Oregon Electric Railway, and other Western railroads.

John Frank Stevens was born at West Gardiner, Maine, April 25, 1853, and while still a young man went to the Middle West, where he was active in railroad engineering for many years.

Yale Branch Electrical Exhibition

An electrical exhibition was held in the Dunham Laboratory of Electrical Engineering on Friday and Saturday evenings, December 12 and 13, 1924. The Yale Branch, American Institute of Electrical Engineers, directed the project. E. H. Eames, Chairman, and J. L. Biach, H. L. Elker, C. D. Geer, Jr., and F. F. Tomaino, Executive Committee. These men headed committees on Publicity, Laboratory Apparatus Demonstrations, Reception, Stunts, and Programs.

There were some two dozen or more specific exhibits assigned to small groups. Each was free to develop its own show. The whole exhibition was an aggregate of simple things, nothing of large proportion was attempted. Excepting a few domestic appliances (borrowed from cordial electric shops) the ordinary laboratory apparatus was used but in many cases it was arranged in some significant way. In the main floor one grouping of generators and switches and meters typified a power plant; in another exhibit different methods of starting and controlling the speed of motors were shown. Variations in lamp brilliancy or speed were utilized in a novel sign in which a blue *Y* alternated in brilliancy as its background of white lamps also alternated, one being bright when the other was dim. Another exhibit displayed the electric system supplementing a noisy Ford automobile motor.

Some fields of antiquated Edison dynamos were inverted and served for illustrating "fundamentals." A little lamp post 6 inches high could be placed anywhere on a large map of Connecticut lying on a table, but the lamp would light only over New Haven. There was a duck pond with magnetically controlled ducks, a top that would spin continuously, a "cold stove" where eggs were boiled on a cake of ice, and a tin can induction motor. A toy train operated from a miniature substation with transmission line, transformers, switchboard, and synchronous converter. A radio set, telegraph line, and an automatic telephone exchange were in operation. A lecture room oscillograph, with Professor Turner's new "Transient Visualizer" (which he recently described in a paper for which he received a prize given by the Northeastern Section of the American Institute of Electrical Engineers) showed the transient current which flows when a circuit containing a condenser, a coil, and a resistance is connected to a direct-current circuit. Other electrical exhibits too numerous to mention were shown.

The introduction of extra curriculum methods into laboratory practise brought out surprising capability and independence in organization, creation and execution. There was a stream of about 450 visitors on each evening and it was quite a task to explain to the novice things which were in many cases new to the demonstrator himself.

The exhibition was open to all members of the University for both evenings, and invitations for Saturday evening were sent to A. I. E. E. members, high schools, industrial organizations, and various other groups. Many out of town visitors were present on both evenings.

University of Illinois Establishes Graduate Assistantships

To assist in the conduct of engineering research and to extend and strengthen the field of its graduate work in engineering The University of Illinois maintains fourteen Research Graduate Assistantships in the Engineering Experiment Station; two other such Assistantships are established under the patronage of the Illinois Gas Association. The annual stipend for these is $600, with exemption from all but the matriculation and diploma fees; open to graduates of all American and foreign universities. Nominations are made by the Executive Staff of the Station, and approved by the President of the University. The Engineering experiment Station, organized within the College of Engineering, has been established since 1903 for the study of problems of importance to engineers as well as manufacturing and industrial research work. Its field is almost unlimited in application, embracing all branches of the engineering profession. Communications may be addressed to The Director, Engineering Experiment Station, University of Illinois, Urbana, Illinois.

Students Inspect Battleship

The student branch of the University of Southern California accompanied Professor Biegler on an inspection trip to the Battleship U. S. S. Colorado, Dec. 17th, as guests of Lieutenant Commander Leighton, Chief Engineer Officer. Forty-six engineers took advantage of this opportunity to investigate thoroughly the turbo-generator power plant of this electrically driven ship. The U. S. S. Colorado being the latest electrically driven dreadnaught, offered the students an extensive field to study the latest developments and applications of the principles of marine power plant construction and operation.

Institute of Radio Engineers Elects New Officers

For the year of 1925, the Institute of Radio Engineers has elected the following officers: J. H. Dellinger President; Donald McNicol Vice-President; Alfred N. Goldsmith Secretary and W. F. Hubley Treasurer. Managers elected for the next term of service are: Melville Eastham, A. E. Reoch, H. W. Nichols, A. H. Grebe, L. A. Hazeltine, Lloyd Espenschied, J. V. L. Hogan, J. H. Morecroft and Edward Bennett.

The Institute is an International organization established in 1912 with a membership now of about three thousand.

The Bell Telephone Laboratories, Inc.

On January 1, 1925 were organized, for the purpose of carrying on development and research activity in communication and allied fields The Bell Telephone Laboratories, Incorporated. This new company is owned jointly by the American Telephone and Telegraph Company and the Western Electric Co. Inc., with personnel, buildings and equipment from the research laboratories of the two companies. Extensive laboratory facilities are already under way, with new buildings, covering almost a quarter of a city block, to be added to the 400,000 sq. ft. already in service at 463 West Street, New York City. At date of corporation, the personnel approximates 3600, two thousand of whom are members of the technical staff made up of engineers, physicists, chemists, metallurgists and experts in their various fields.

The chairman of the board of directors is General J. J. Carty, vice-president of the American Telephone and Telegraph Co., and other members of the board are Doctor F. B. Jewett, former vice-president of the Western Electric and recently elected vice-president of the Am. Tel. & Tel., President of the new corporation; W. S. Gifford, President of the American Telephone and Telegraph Co.; Bancroft Gherardi, vice-president of the same Company; C. G. DuBois, president and J. L. Kilpatrick, vice-president of the Western Electric Co. and J. B. Odell, Assistant to the president, Western Electric Co.

The operations of the Bell Telephone Laboratories will be under the direction of E. B. Craft, executive vice-president,—formerly chief engineer of the Western Electric Co.

In the functional division of the research development and engineering work of the Laboratories, physical and chemical research is organized under Dr. H. D. Arnold, Director of Research; development of apparatus under Mr. J. J. Lyng, Apparatus Development Engineer, and development of communication systems under Mr. A. F. Dixon, Systems Development Engineer, all experienced men in similar activities in the Engineering Department of the Western Electric Company. Dr. R. L. Jones, Inspection Manager, continues his responsibilities in engineering inspection, and S. P. Grace, Commercial Development Engineer, cares for the commercial development.

The patent work of the Laboratories is organized under Mr. J. G. Roberts, General Patent Attorney, former Assistant General Patent Attorney of the Western Electric Company.

The corporate and commercial relations of the Laboratories are under the direction of vice-president E. P. Clifford who was commercial manager of the Engineering Department of the Western Electric Company. John Mills continues as Personnel Director, in charge of personnel activities, and educational and college relations.

The formation of the special Laboratories is an indication of the importance which these companies place upon properly organized research and is a promise of continuous service to the public, to the communication art and to the progress of science.

Annual Tables of Constant and Numerical Data

Volume V of the "Annual Tables of Constant and Numerical Data—Physical, Chemical, and Technological,"—containing data for the years 1917 to 1922,—is now on the press.

These Annual Tables are published by an International Commission, under the authority of the International Research Council and the International Union of Pure and Applied Chemistry. They were founded in 1910, completion of this fifth volume being interrupted by the war. It will now be continued,

including data which has been published during the current year, in complete but non-critical form. The Annual Tables are published in Paris, supported by an international budget raised by government contributions and scientific and engineering societies throughout the universe. The Institute is one of these contributors, and members may obtain copies of the Tables at reduced special rates. Address University of Chicago Press, Chicago, Illinois, mentioning membership in the Institute.

Architectural and Allied Arts Exposition

The Architectural and Allied Arts Exposition will be held at the Grand Central Palace, New York, N. Y., April 20th to May 2, 1925. In addition to a comprehensive display of materials which make for the home, factory and businesss building, there will be home decoration, decorative tapestries, examples of landscaping, etc. The Annual International Conference on City Planning will be held within the Exposition and the Architectural League will unite with the American Institute of Architects holding their display in conjunction with the exposition.

Westinghouse Electric Makes Changes

F. A. Merrick, vice-president and general manager of the Canadian Westinghouse Company, Hamiliton, Ont, has been elected vice-president and general manager of the Westinghouse Electric and Manufacturing Company. He will have offices at East Pittsburgh and assume his new duties January 1st.

The office of the president, E. M. Herr, has been removed from East Pittsburgh to the Westinghouse Building, 150 Broadway, New York City.

Mr. Merrick shortly after his graduation from Lehigh University was employed by the Steel Motors Company, a subsidiary of the Lorraine Steele Co.; here he contributed many important electrical inventions of his own, and rose to the position of Chief Engineer. Later he joined the Westinghouse Electric & Mfg. Co., East Pittsburgh, to take charge of production of street railway motors. Upon the formation of the Canadian Westinghouse Company, Ltd., he was sent there as superintendent later becoming Works Manager and finally, vice-president and general manager. During the World War, he was in charge of munitions production at Chicopee Falls for the Russian Government and later our own government requirements for the famous Browning machine gun. With reorganization and reequipment, Mr. Merrick was able to turn out 60,000 guns within eleven months of the first operations, an achievement which, in the industrial world, is considered without parallel.

President Herr is leaving Pittsburgh after having served there since 1899. He, too, has achieved a notable place in industry. Graduating from the Sheffield Scientific School, Yale, in 1884, he served a special apprenticeship with the Chicago, Milwaukee and St. Paul Railway in their motive power department, later becoming test engineer and superintendent of telegraphs and ultimately superintendent of the Burlington Railroad. In 1890 he was appointed master mechanic on the C. M. & St. P. and in 1892, superintendent of the Grant Locomotive Works in Chicago. In 1895 he was in Russia, establishing locomotive works there. Upon his return he went with the Gibbs Electric Co., as superintendent, and thence with the Chicago & Northwestern R. R. as superintendent of motive power. In 1899 he entered the employ of the Westinghouse Company and after various promotions, was elected to the presidency in 1911.

Electrically Driven Auxiliaries for Steam Generating Station

The problems of the utilization of electrically-driven auxiliaries in steam generating stations are covered in a report entitled "Electrically Driven Auxiliaries for Steam Generating Stations" prepared by the Electrical Apparatus Committee of the National Electric Light Association, and just published by them.

The report comprised of 136 pages and cover contains 95 illustrations, and is a handbook on central station practice in the use of these auxiliaries. The information, collected by a special subcommittee of which N. L. Pollard of the Public Service Production Company, Newark, N. J., was chairman, was obtained from practically all large central stations in the United States a special feature of the report being a symposium on the auxiliary practise of 39 modern steam plants in this country. Although it was necessary to limit this report primarily to coal-burning stations, housing generating units of at least 20 000-kw.-capacity, two oil-burning plants were included, as it was thought that the method of driving the condenser auxiliaries, etc., would be of interest to the profession.

The report is divided into four sections as follows:

Section 1, presenting the requirements of the various auxiliaries, tabulated by class to show the average practise. The idea was to gather into one class all replies giving the same general allowable time of interruption, variation of speed, number of steps of speed control, and duplication of apparatus.

Section 2 contains a description of the types of motors and control available.

Section 3 outlines various sources of electric power used for driving auxiliaries, with a discussion of the merits of the different sources.

Section 4 consists of data and diagrams indicating methods used in driving the auxiliaries in 39 modern American steam generating stations.

In addition, there are four articles not yet published in the technical press written by manufacturers of electrical equipment: on (the following subjects)

Considerations in the Application of Motor Driven Circulating Pumps.

Comparison of Various Methods of Driving Forced Draft Fans.

Mechanical Stokers.

Typical Motor Installations for Coal Handling Equipment.

A bibliography is also included.

Copies of the report may be ordered from N. E. L. A. headquarters, 29 West 39th Street, New York, N. Y., the price to members of the N. E. L. A. being 90 cents; to non-members $1.35, post paid. For purchases in quantity, mailed to one address, discounts from these basic prices are as follows:

11-25 copies	5 per cent
26-50 copies	10 per cent
More than 50 copies	15 per cent

Members' prices to colleges and public libraries.

Organizations should order on their purchase forms and remittance should accompany all orders from non-member individuals.

PERSONAL MENTION

Communication from Reginald A. Gladwell, Rugby, England, states that he is about to take position as Commercial Engineer on the Melbourne Office staff of the Australian General Electric Company.

Frederick Frolich is now working with the New York State Bridge and Tunnel Commission, with offices in the Woolworth Building, having left the Dwight P. Robinson Co., the later part of December last.

Edward T. Moore announces the opening of his own office at 500 Cahill Building, Syracuse, New York, in the practice of consulting engineer. Mr. Moore was previously with the Halcomb Steel Company of that city.

Walter W. Reed has been appointed assistant engineer of the New York and New Jersey Bridge and Tunnel Commission,

Woolworth Bldg., New York, having resigned from his previous connection with Dwight P. Robinson & Company.

William H. Rose has withdrawn from the vice-presidency of the American Machine & Foundry Company, this city, and has removed to Chicago to affiliate himself with Lockwood, Greene & Company, Engineers, First National Bank Building, Chicago.

R. H. Horton has resigned from his position as vice-president of the International Railway Company, Buffalo, New York, and has accepted the office of President of the Philadelphia Rural Transit Company, operating the motor bus lines in that city.

Marvel M. Golden, electrical engineer, Constructions Electriques de France, Paris, has been appointed to represent them in a French Government Economical Mission to Japan. Mr. Golden leaves France about the first of February, but his mail address will remain 9 Rue Pergolese, Paris.

George L. Hedges, who has been doing mechanical designing engineering work at East Cleveland, Ohio, has associated himself with his uncle in the Hedges Lincoln Iron Works, Lincoln, Neb., one of the oldest companies of its kind in that section, having been established by Mr. Hedges' grandfather in 1873.

Archibald H. Kinghorn, Jr., has left his position as assistant engineer for the Bell Telephone Co., Philadelphia, and has established new connections with the Philadelphia and West-Chester Traction Co., Upper Darby, Pa., where he will serve in the capacity of assistant to the second vice-president.

Donald McNicol, who resigned from the service of the Radio Corporation of America last March to become identified with the Pneumatic Tube Supply Company, has recently been elected vice-president of that Company. The main office and works are located at Plainfield, N. J., with district offices in New York, San Francisco and Toronto, Canada.

On January 21st, the Norman Medal,—highest award of the American Society of Civil Engineers,—was bestowed upon Bernard Faaborg Jakobsen, Member of the Institute since 1913. For many years, Mr. Jakobsen has been consulting engineer with offices at 1405-6 Chronicle Building, San Francisco, California, and the medal was conferred at the Annual Convention of the American Society of Civil Engineers recently held in New York.

Henry W. Blake, who has been with the *Electric Railway Journal* since 1891, retired January 1st, succeeded by Mr. Morris Buck. As an editor, Mr. Blake has for many years been pre-eminent in the field of technical journalism, and has been with this paper practically since its inception. He was graduated from Yale in 1886 with a C. E. degree, entered an electrical course at the Massachusetts Institute of Technology, upon the completion of which he took a position with the Sprague Electric Railway & Motor Company, engaged in the construction of electric railways in various cities of the United States. His progress might well be paralleled with the advancement of the *Electric Railway Journal* itself.

E. B. Craft, formerly Chief Engineer of the Western Electric Company, has been appointed Executive Vice President of the Bell Telephone Laboratories, Incorporated, and will be in direct charge of the research and development activities of that organization. During the twenty-three years of his association with the Western Electric Company, he has contributed materially to the development of the art of communication, having been granted more than seventy patents relating to telephone systems and apparatus. Mr. Craft is Chairman of the Headquarters Committee and a former member of the Board of Directors. He is also a member of the Library Board of United Engineering Society, Vice-Chairman of the Division of Engineering and Industrial Research of National Research Council and a Fellow of American Institute of Radio Engineers.

Morris Buck, for the last two years associate editor of the *Electric Railway Journal*, has now been made managing editor. Mr. Buck has accomplished much important investigation of electric railways throughout the country, studying the properties of these in Boston, Eastern Massachusetts, New York, Philadelphia, Washington, Newark, Richmond, Chicago, Kansas City, New Orleans and others, the work involving a wide range of operating engineering as well as financial problems for railways and public officials. For six years before taking up the consulting work, Mr. Buck was assistant professor of electrical engineering at the University of Illinois, at which time he became well known in the field of electric railway engineering for original work done in the solution of problems by graphical methods. Other years of teaching included professorship at the Clarkson College of Technology, two years as assistant professor at the New Hampshire State College and one year as instructor at Cornell University, from which he had graduated in the mechanical engineering class of 1904. Mr. Buck graduated from the University of Illinois, with the 1917 class.

Obituary

On the 25th day of December, 1924, A. Gero Schmidt, died at his home, 22 Carey Avenue, Wilkes Barre, Pa. Mr. Schmidt was born in Rome, Italy. He was a graduate of the Karlsruhe University, Germany. In 1912-14 he served an apprenticeship course at the Westinghouse works, Pittsburgh and in 1914 was made sales engineer, export department of the British Westinghouse Electric & Mfg. Co., Ltd., Manchester, England. In 1915-19 he served as an officer in the Italian Army, Engineers Corps and upon the termination of the war in 1919, was made Assistant to Manager and Chief Engineer, Societa Laziale di Elettricita, Rome, Italy. Mr. Schmidt was also a member of the Associazione Nazionale degli Ingegneri Italiani, Rome.

Dr. Nathaniel S. Keith, a charter member of the Institute and its first secretary, died suddenly in Philadelphia, on January 27, aged eighty-seven.

Dr. Keith was born in Boston July 14, 1838. He was educated as a chemist in his father's chemical laboratory, New York City, and was engaged as investigator, inventor, editor, and electrical engineer since 1870. He was one of the most active in the small group of men whose conferences finally brought about the organization of the Institute in 1884. He was one of the members of the Electrical Conference held in Philadelphia in 1884, and was a judge at the Philadelphia Electrical Exhibition in the same year. For many years past Dr. Keith has been in business in Philadelphia as a consulting engineer.

James A. Brett, Manager of the Cincinnati Office of the Westinghouse Electric and Manufacturing Company for nearly twenty years, died suddenly at Bermuda, January 6th, 1925. Born at Mount Vernon, New York, July 24th 1866, Mr. Brett's early education was through the public schools, and his business career was started as telephone operator and inspector in that city. In 1886 he took a position with the Sprague Electric Railway and Motor Co. as an apprentice in their New York City shops. By 1889, Mr. Brett has achieved a superintendency in charge of electric railway construction for the Sprague Electric Railway & Motor Co., the Edison General Electric Company and the General Electric Co. In 1892 he left New York to become general superintendent of construction of the Detroit Electrical Works and in 1893 was made superintendent, general superintendent and general manager of the Electrical Installation Co. of engineers and contractors, Chicago, Ill. It was from this position he resigned in 1904 to identify himself with the Westinghouse Company, with whom he was at the time of his death.

AMERICAN ENGINEERING COUNCIL

ANNUAL MEETING, WASHINGTON, JANUARY 16-17

The annual meeting of the American Engineering Council was held in Washington, D. C., January 16-17, 1925. About one hundred delegates of the twenty-nine societies represented upon Council were in attendance, and President James Hartness presided. The representatives of the A. I. E. E. present were Messrs. C. A. Adams, C. G. Adsit, Arthur W. Berresford, John H. Finney, F. L. Hutchinson, D. C. Jackson, William McClellan, Farley Osgood, Charles F. Scott, and C. E. Skinner.

The officers elected were Vice-Presidents Arthur W. Berresford, Niagara Falls, N. Y.; D. S. Kimball, Cornell University, Ithaca, N. Y.; O. H. Koch, Dallas, Tex., and Treasurer (reelected) H. E. Howe, Washington, D. C. Hold-over officers are: President, Honorable James Hartness, Vermont; Vice-President, Gardner S. Williams, Ann Arbor, Mich.

Addresses regarding the activities of the society were made by President Hartness and Executive Secretary L. W. Wallace. Reports of the treasurer, auditor, and Finance Committee were presented and other routine matters disposed of. The Little Rock Engineers' Club was elected to membership.

Announcement was made of the names of the representatives who will constitute the Administrative Board for the year 1925 consisting of the President, four Vice-Presidents, the Treasurer, fourteen representatives of national societies, and eight regional representatives—the delegation to represent the A. I. E. E., in addition to Vice-President Berresford, being composed of Messrs. C. G. Adsit, Atlanta, Ga.; John H. Finney, Washington, D. C.; D. C. Jackson, Boston, Mass.; L. F. Morehouse, New York; Charles F. Scott, New Haven, Conn.; and C. E. Skinner, Pittsburgh, Pa.

Among the important matters discussed were the following: Changes in the Government Reorganization Bill as it affects the Department of the Interior were urged and it was decided to join with other national bodies in seeking amendments to the existing bills in the House and Senate. A resolution was adopted urging that the proposed legislation be amended so as to bring it into substantial accord with the principles embodied in the old Jones-Reaves Bill originally sponsored by the engineering profession through the National Public Works Department Association. The Council ratified the action of the Administrative Board in continuing the participation of Council with the National Board for Jurisdictional Awards which settles disputes among unions in the building industry. Rudolph P. Miller of New York was appointed to represent Council on the Jurisdictional Board of which he is now chairman. Reforestation and timber supply, and street and highway safety were among other important subjects discussed.

A notable event of the meeting was the annual dinner on the evening of January 16, at the Chevy Chase Club. President Hartness presided and addresses were made by General Herbert M. Lord, Director of the Budget, and the Honorable Herbert Hoover, Secretary of Commerce. Mr. Hoover said in part:

"Those of you who will go back five years to the time when we first instituted the American Engineering Council will recall that our first large activity in research was in the subject of 'waste.' That was indeed a work of national importance, and for the first time it had been brought to the attention of the engineers, the scientists and the public that something was wrong in our economic system.

"The Department of Commerce took up the work of making effective, so far as might be within the limitations imposed by the director of the budget, the possible accomplishment outlined by that Engineering Council investigation directed from New York City.

"I might say that we have actually spent something like $100,000 a year in that work, and to-day by careful cultivation, by an infinite amount of negotiation and conferences, by striking at this problem in every conceivable direction, I have no hesitation in saying that the reduction in waste in our economic system exceeds $600,000,000 per annum.

"The establishment of standards, the economies which they bring in production and distribution; the elimination of unnecessary varieties, the establishment of specifications, the vast improvement in our statistical services and the stability they give to business, have all of them contributed amounted estimated by those engaged in industry to far exceed the figures which I have given to you, and I think we spent but about $100,000."

On Thursday, January 15, there was an all-day conference of about thirty secretaries of local and national engineering societies, which had been arranged under the auspices of American Engineering Council for the purpose of affording an opportunity for the secretaries to discuss the many problems of mutual interest. Mr. Charles E. Billin, Secretary of the Philadelphia Engineers' Club, presided, the meeting developing into an exceedingly interesting and profitable discussion on the work of the various societies and best methods of cooperation.

COMMITTEE TO STUDY AIRCRAFT SITUATION

The appointment of a committee to study the entire aircraft situation has been announced by the Engineering Council. The chosen chairman is Joseph W. Roe, professor of Industrial Engineering, New York University.

President Hartness states that it will be the work of this Committee to inquire into all phases of air navigation,—particularly the air mail,—and a large group of related questions to be taken up. The Committee's report to the Council is expected to serve as a guide to their future policy in the aeronautical field.

Professor Roe is former president of the Society of Industrial Engineers and came to New York University from the faculty of the Sheffield Scientific School, Yale University. He is a former member of the Council and during the war was stationed at McCook Field, Dayton, O. Other eminent members of the committee are Doctor W. F. Durand, President of the American Society of Mechanical Engineers; who served during the war on the National Advisory Committee on Aeronautics; Prof. E. P. Warner, of Massachusetts Institute of Technology, Chairman, of the A. S. M. E. Committee on Aeronautics; Geo. W. Lewis executive officer of the National Advisory Committee on Aeronautics, Washington; Starr Truscott, design expert, Naval Bureau of Aeronautics, Washington; W. B. Stout, airplane manufacturer, Detroit; Chas. M. Manly, New York; Col. A. T. Perkins, St. Louis; Howard E. Coffin, Detroit; and G. C. Spaulding of Spokane, Washington.

American Engineering Standards Committee

INDUSTRIAL STANDARDIZATION

Looking toward worldwide work along standardization lines, the American Engineering Standards Committee elicit cooperation with all interests, both here and abroad. The importance of the work of standardization is becoming more and more pronounced; already 70 standards have been approved by the A. E. S. C. and 100 others are under way. In the mining world, the pioneer work was done by the U. S. Bureau of Mines and then the American Mining Congress. The work of the National Screw Threads Commission in the mechanical field, has also been of great importance. And Standardization carries heavily into public safety questions such as the unification of colors in traffic signals, etc. Secretary Hoover contends that in the general problem the number of fatalities is one third, and those wounded, one and one half times the corresponding American losses in the World War which is certainly a fact in emphasis of the importance of standard safety measures. A program of 40 industrial safety codes, most of which are applicable to factories is underway; Thirteen have been completed and the remainder are well advanced. This includes lighting and other work done in schools. Standardization activities in foreign industrial countries continue to increase, among the newest national organizations are those in Czechoslovakia and Japan.

In all, there are nineteen national standardizing bodies, as follows: Australia, Austria, Belgium, Canada, Czechoslovakia, Finland, France, Germany, Great Britain, Holland, Hungary, Italy, Japan, Norway, Poland, Russia, Sweden, Switzerland and the United States. The vital importance of the work cannot be overestimated.

ENGINEERING FOUNDATION

ENDOWMENT FOR ENGINEERING FOUNDATION

If our country is to continue its beneficient progress, the advance of the engineering profession cannot be slackened is the sentiment voiced by Alfred W. Flinn, Director of the Engineering Foundation. If professional progress is to continue, the national societies must have the benefit of a sustained, considered, coordinated program of research, and for this, large funds are needed.

One engineer, Ambrose Swasey, has already made a very generous beginning by his gift of half a million dollars for the Engineering Foundation's endowment, and recently another engineer, Henry R. Towne, by his will added fifty thousand dollars to this fund. But Farley Osgood, President of the American Institute of Electrical Engineers, urges an increase of this endowment to the amount of twenty million dollars. Others concur with his suggestion as being in scale with the American engineering body and the importance of the service to which they aspire for this country. If the engineering body is in earnest, it can be done.

On January 7th, the presidents and secretaries of the Founder Societies and the United Engineering Society, began the study of plans for redoubled effort to increase the resources of the Foundation. But to accomplish even a fractional part of the anticipated service, far greater funds are needed. Further information will be given to members of the societies as the plans develop toward the desired end.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES DECEMBER 1-31, 1924

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Book of the Locomotive.

By G. Gibbard Jackson. Lond. & N. Y., Longmans, Green & Co., 1924. 244 pp., illus., col. pl., 8 x 5 in., cloth. $2.00.

Records the history of the British locomotive, from Murdoch's model of 1784 to the mammoth engines of today, describing the advances made by various designers and showing the gradual evolution very satisfactorily. Written simply and without great technical detail, it is suited to non-technical readers as well as to those with special interest in the subject. Many illustrations, including some in colors.

Ce Que Tout Aviateur Doit Savoir.

By André Lainé. Paris, Gauthier-Villars et Cie. [1924]. 173 pp., illus., diagrs., 8 x 5 in., cloth. 12 fr.

A convenient handbook for aviators, prepared by an experienced instructor and adapted to the official program of instruction in military aeronautics of the French government. Treats of mechanics and aerodynamics; the construction, maintenance and proving of aeroplanes; the motor and propulsion system; atmospheric phenomena and their consequences for the aviator; and instruments. These subjects are covered concisely, with special reference to the information most needed by the aviator.

Conferences Scientifiques.

By Albert Turpain. Paris, Gauthier-Villars & Co., 1924. 5 v., illus., 8 x 5 in., paper. 5 fr. each.

v. 1.—Le nouveau domaine de l'électricité.—L'évolution des théories électriques.

v. 2. L'éclairage et le chauffage électrique.—La naissance d'une lampe a incandescence.

v. 3.—L'air liquide.—Le froid industriel et son utilisation.

v. 4.—De la presse a bras a la linotype et a l'électrotypographe.

v. 5.—Le cinématographe.

In these five small volumes Professor Turpain publishes a series of lectures which he has delivered from time to time before various audiences in France. These addresses dealt with various scientific and technical matters, reviewing their history, describing their development and expounding their theory. Intended for general audiences rather than for specialists, the lectures are admirable examples of the popular presentation of technical information.

Dynamo Electric Machinery.

By Erich Hausmann. N. Y., D. Van Nostrand Co., 1924. 645 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.50.

This textbook covers both direct-current and alternating-current and is intended to supplant the two textbooks on those subjects written by the author in collaboration with the late Dr. Samuel Sheldon. It is intended for students in electrical courses but may also be used as a basis for courses to students of other branches of engineering, and for reference by engineers whose work involves the use of electrical machinery.

Einfuhrung in die Elektrotechnik.

By C. Heinke. 2nd edition. Berlin u. Leipzig, Walter de Gruyter & Co., 1924. 490 pp., illus., diagrs., 9 x 6 in., cloth. 18 g.m.

An introduction to electrical engineering for serious students Written on broad lines, it pays attention both to the scientific principles involved in the design and applications of electrical machinery and to modern methods of construction, so that it is well adapted to give a general view of the subject as a whole. The book reproduces Dr. Heinke's lectures to students of electrical engineering in the Munich Technical High School.

Electric Wiring; a Textbook....for Vocational and Trade Schools.

By Albert A. Schuler. N. Y., McGraw-Hill Book Co., 1924. 361 pp., illus., 8 x 5 in., cloth. $2.50.

A textbook arranged according to unit system now favored by many teachers. Systematic courses of instruction are provided for each of the various branches of wiring—bell, annunciator, burglar alarm, electric light, house, telegraph, and telephone—by means of graded jobs or exercises which are described and illustrated.

Electrical Vibration Instruments.

By A. E. Kennelly. N. Y., Macmillan Co., 1923. 450 pp., illus., diagrs., 9 x 6 in., cloth. $6.50.

In spite of the enormous number of Bell telephone receivers in use, there has been singularly little information available on the nature and properties of the receiver as a machine. This book aims to present, from an electrical engineering viewpoint, the characteristics of telephone receivers and of other vibrational instruments as reciprocating electric motors. It is based on researches which have been carried on during the past fourteen years at Harvard University and the Massachusetts Institute of Technology.

The book is intended as a text for students of the telephone and as a reference book for telephone engineers. In addition to the telephone receiver, the behavior and tests of oscillographs and vibration galvanometers are discussed.

Elektrische Maschinen. Vol. 1.

By Rudolf Richter. Berlin, Julius Springer, 1924. 630 pp., illus., diagrs., 9 x 6 in., boards. $4.80.

This textbook reproduces, in expanded form, the course of instruction upon electrical machines and transformers, given by Professor Richter in the Karlsruhe Technical High School. It extends to two volumes, of which the first is devoted to the general principles of design which apply to all machines and transformers and to direct-current machinery.

The book omits the calculation of mechanical requirements, as well as the technology of the materials used and the dielectric properties of insulants. The magnetic, electric and thermal reactions in electrical machinery, so far as they are of importance, are gone into very thoroughly. The course set forth includes the results of the newest researches and is supplied with references to original sources.

Elements of Electrical Engineering.

By Arthur L. Cook. N. Y., John Wiley & Sons, 1924. 568 pp., illus., diagrs., 9 x 6 in., cloth. $4.00.

A textbook on the fundamentals of electrical engineering and their application in practice, based on the author's methods at Pratt Institute Suitable as a short course for electrical students and also for non-electrical students in colleges. Discusses the subjects needed most commonly by engineers, but does not attempt to describe all types of electrical machinery. The book is designed to teach fundamental principles rather than to present merely a mass of information. Special attention is paid to magnetic circuits and to alternating-currents.

Enlarged Callendar Steam Tables.

By H. L. Callendar. Lond., Edward Arnold & Co., 1924. 80 pp., tables, 9 x 6 in., cloth. $2.50. (Gift of Longmans, Green & Co., N. Y.)

In response to a demand for more detailed tables at higher pressures and temperatures, the tables have been extended and rearranged on a pressure basis, as being more convenient for reference. The present issue is restricted to tables on the foot-pound-fahrenheit system. The tables for the properties of saturated steam now extend from a vacuum of 29,5 in. by intervals of 0.05 in. at the lowest pressures, to a pressure of 30 in. The table for superheated steam gives the properties from an absolute pressure of 1 lb. per sq. in. and a temperature of 100 degrees to a pressure of 2000 lbs. per sq. in. and a temperature of 1000 degrees. Auxiliary tables have been added of some quantities of use in practical calculations for experimental work.

Introduction to the Economies of Air Transportation.

By Thomas Hart Kennedy. N. Y., Macmillan Co., 1924. 154 pp., illus., 8 x 5 in., cloth. $2.00.

The quality that air transportation offers in greater degree than other forms of transportation is speed. Is the addition of this desirable quality justified from the viewpoint of economics? Is air transportation a profitable business? If not, how can it be made profitable? Mr. Kennedy has devoted himself to a study of these questions and here presents the material that he has been able to collect. He sketches the history and technical features of aircraft, describes the Air Mail Service and the Aeromarine Airways line, as well as projected lines. He includes a record of his experiences as a passenger on European air lines in 1923 and data on European air transport lines and companies.

Ions, Electrons and Ionizing Radiations.

By James Arnold Crowther. 4th edition. N. Y., Longmans, Green & Co., Lond., Edward Arnold & Co., [1924]. 328 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

This is neither a popular exposition of the "new" physics nor a compendius synopsis of the subject. It is intended as a textbook for students who have been grounded in the more elementary portions of physics and who wish to obtain a systematic knowledge of its latest developments. To facilitate this, the present work selects from the great mass of researches and theories those which are most fundamental and best established, and arranges them in the most straightforward and easy order.

The new edition has been thoroughly revised and enlarged. Parts of the subject that have become more prominent have been expanded, while sections of diminishing importance have been compressed or eliminated, so that the new edition reflects the point of view of the present day.

Isotropes.

By F. W. Aston. 2d edition. N. Y., Longmans, Green & Co., 1924. 182 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.50.

Dr. Aston here presents a convenient account of the discovery of isotropes and of the methods by which they are studied, together with a summary of the results that have been obtained. In the new edition he has included the great advances that have been made since the first publication of the book, bringing it thoroughly up to date.

Die Kommutatormaschinen.

By M. Schenkel. Berlin u. Leipzig, Walter de Gruyter & Co., 1924. 259 pp., illus., diagrs., 9 x 6 in., paper. 10, 50 mk.

This book, which is based on twenty years of experience with the alternating-current commutator motor, is designed to meet the want of a practical book on that subject. The first three chapters summarize the practise in the whole field, without consideration of the theory. The next four chapters present the common principles of all commutator motors, while the last nine chapters treat of the peculiarities of the various types. The book is confined to modern motors that have proven satisfactory commercially. A bibliography is included.

A Long Life's Work, an Autobiography.

By Sir Archibald Geikie. Lond., Macmillan & Co., 1924. (Gift of N. Y. Macmillan Co.). 426 pp., ports., 9 x 6 in., cloth. $7.00.

Sir Archibald Geikie was born in Edinburgh in 1835 and educated in that city. Early attracted to geology, he entered Geological Survey in 1855 and began his long connection, which did not end until 1903, when he retired as Director-General. The next ten years were occupied by duties, first as Secretary, then as President, of the Royal Society. His autobiography is an interesting, modest account of his personal life and scientific career, containing much to interest the geologist.

Magnets.

By Charles R. Underhill. N. Y., McGraw-Hill Book Co., 1924. 468 pp., illus., diagrs., 9 x 6 in., cloth. $4.00.

The object of this book is to treat broadly the general principles of electromagnetically controlled and operated apparatus and to treat in detail electromagnets and permanent magnets. Hence, the materials used in magnets, the relative dimensions of the various parts, and the phenomena associated with them, are carefully considered. Since electromagnetic devices are controlled by alternating or direct current circuits, these general circuits and their phenomena are explained. The book covers the field more thoroughly than any other existing treatise.

Mathematics for Technical Students.

By E. R. Verity. Lond. & N. Y., Longmans, Green & Co., 1924. 468 pp., 9 x 6 in., cloth. $4.00.

A textbook planned to meet the standard required for the "Senior Course" Certificate in Engineering awarded by the Institution of Mechanical Engineers. The course covers algebra, trigonometry and the differential and integral calculus, and is intended for students with some knowledge of geometry.

Matter and Change.

By William C. D. Whetham. Cambridge, England, University Press, 1924. 280 pp., illus., diagrs., 8 x 5 in., cloth. $2.50. (Gift of Macmillan Co., N. Y.)

This book is well adapted for use by those who wish an introduction to deeper study, or those, with main intellectual interests

in other fields of thought, who wish some knowledge of the chief physical concepts by which our knowledge of nature is interpreted. The author explains the essential methods and principles of physics and chemistry clearly, with only elementary mathematics, and illustrates matters by examples that are drawn from or lead up to the more important results of recent research.

METALLURGY OF COPPER.

By H. O. Hofman. 2nd edition, revised by C. R. Hayward. N. Y., McGraw-Hill Book Co., 1924. 419 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

This treatise covers the entire subject of the metallurgy of copper and attempts to present the subject in a manner which will meet the needs of the metallurgist. The leading physical and chemical facts about the metal, its alloys, and its compounds which are of metallurgical importance are presented; those portions of older practice which are of lasting value are recorded; and the details of present method of operating are given. The revision has been made by Professor Hayward, who was closely associated with Dr. Hofman for twenty years. It takes account of such important changes in practice as the development of the reverberatory smelting furnace, the use of the basic converter and the installation of large hydrometallurgical plants.

MOON-ELEMENT; An Introduction to the Wonders of Selenium.

By E. E. Fournier D'Albe. N. Y., D. Appleton & Co., 1924. 166 pp., illus., 9 x 6 in., cloth. $3.00.

This, the author states, is the first connected account of the properties and applications of selenium. It describes the development and manufacture of selenium cells, discusses the nature of the action of light on selenium, its use in control apparatus, in the transmission of pictures, in talking films and in the conversion of light into sound. The history of the optophone, the apparatus invented by the author which enables the blind to read printed books, is given in full.

LE VOL A VOILE DYNAMIQUE DES OISEAUX.

By Louis Breguet. Paris, Gauthier-Villars et Cie., [1925]. 57 pp., 9 x 6 in., paper. 8 fr.

In this memoir, the author has attempted to establish rationally the first principles of flight in agitated air, limiting his discussion to a fundamental study of the mean rectilinear and horizontal motion of a plane subjected to periodic pulsations of the air, such as occur in winds. The problem is attacked by methematical analysis. The theory developed is that proposed by the author in 1909, which differs from those of Mouillard and Langley and of Sée.

RECENT DEVELOPMENT OF PHYSICAL SCIENCE.

By William C. D. Whetham. Phila., P Blakiston's Son & Co., 1924. 313 pp., illus., ports., 8 x 5 in., cloth. $3.00.

Intended as a short account of some of the important investigations now being carried on in the physical laboratories of the world, this book discusses such questions as the philosophical basis of physical science, the liquefaction of gases, fusion and solidification, solution, the conduction of electricity through gases, radio-activity, matter, space and time, and astro-physics. It is intended for students of science in general. to whom it offers a summary of work in other departments than their own, and for those without scientific training who are interested in the more important conclusions of scientific thought.

The edition has been thoroughly revised, partly rewritten, and enlarged.

STORY OF COPPER.

By Watson Davis, N. Y., Century Co., 1924. 385 pp., illus., diagrs., 8 x 5 in., cloth. $3.00

The author has succeeded in presenting the history of copper, its occurrence, mining, metallurgy, chemistry, and uses, in an interesting manner and in language that any intelligent reader can understand, yet without sacrificing accuracy. His aim is to increase popular appreciation of the importance of the metal. References to more technical works are provided for those who wish detailed information on any phase of the subject.

STORY OF EARLY CHEMISTRY.

By John Maxson Stillman. N. Y., D. Appleton & Co., 1924. 566 pp., 9 x 6 in., cloth. $4.00.

The pioneers in the history of chemistry devoted much able labor to early developments in the growth of the science. Later historians have laid the emphasis upon more modern developments and have depended largely upon the earlier histories for their summaries of early chemists.

In the mean time, however, much serious attention has been given to ancient and medieval writers by some modern scholars and their conclusions have altered the story of the growth of chemical knowledge in important respects. For this reason, Dr. Stillman thought it important to rewrite the history of early chemistry, in the light of these new investigations.

He gives a connected, systematic account of the development of chemical knowledge and science, from the earliest times to the close of the eighteenth century. No attempt to be encyclopedic is made, but emphasis is placed upon the discoveries and speculations that have had a decided effect on the growth of the science and upon the chemists who have been of real significance.

STRUCTURAL ENGINEERING, [v. 2]; Fundamental Properties of Materials.

By George Fillmore Swain. N. Y., McGraw-Hill Book Co., 1924. 200 pp., illus., diagrs., tables, 9 x 6 in., cloth. $2.50.

This, the second volume of Dr. Swain's treatise in structural engineering, is not intended to replace detailed works on materials nor to describe processes of manufacture. It is intended to bring together in logical fashion the information needed by the constructing engineer concerning the fundamental properties of the principal materials, their constitutions and physical structures, the importance and effect of various ingredients, the effect of different treatments and the significance of the specifications used to secure desired properties in them.

THOMAS ALVA EDISON.

By Francis Arthur Jones. N. Y., Thomas Y. Crowell Co., 1924. 399 pp., illus., ports., 8 x 5 in., cloth. $3.00.

A popular anecdotal account of Edison, which deals primarily with the man rather than with his inventions, although the latter are not neglected. This edition has been revised, reset and continued down to the present year.

UBER DIESEL-ELEKTRISCHE LOKOMOTIVEN IM VOLLGAHNBETRIEB.

By Herbert Brown. Zürich, Ernst Waldmann, 1924. 73 pp., diagrs., tables, 9 x 6 in., paper. (Price not given.) (Gift of Brown, Boveri & Co., Baden, Switzerland.)

The Diesel engine is, the author of this work says, the most economical heat engine of today. It is therefore very desirable that it be also used for locomotives. The problem has been solved for light locomotives, but not for those for trunk lines and the purpose of the present study is to test suitability of the Diesel engine for heavy locomotive work.

In part 1, the pamphlet reviews briefly the various kinds of Diesel locomotives which have been proposed. The remainder of the book is concerned with exact investigations of the Diesel-electric locomotive, the type most favored at present. This type is examined theoretically and practically, from both a technical and an economic viewpoint.

SUBSTATION OPERATION.

By Edwin Kurtz. N. Y., McGraw-Hill Book Co., 1924. 261 pp., illus., diagrs., 8 x 6 in., cloth. $2.50.

An elementary textbook intended for men engaged in actual substation operation who wish to acquire a knowledge of principles and methods. Treats of station layout and wiring, the names and functions of the machines and auxiliary apparatus, station records and their purposes, methods and purpose of circuit tests, safety equipment and its use, accident prevention and first aid. Written in language that is easily understood.

TELEGRAPHY AND TELEPHONY WITH RAILROAD APPLICATIONS.

By Charles Stanley Rhoades. N. Y., Simmons-Boardman Publishing Co., 1924. 518 pp., illus., 7 x 5 in., cloth. $4.00.

While the principles of telegraphy and telephony are the same for commercial and railroad service, there are differences in practise. This manual is written for beginners in railroad work and is intended to give a knowledge of the principles, of the telegraph and telephone plant and service, for the organization and of the methods used in practise to meet the engineering and operating problems that arise in railroad work.

THERMODYNAMIQUE.

By J. A. Ewing. Trans. by M. R. Duchêne. Paris, Gauthier-Villars et Cie., 1924. 488 pp., diagrs., tables, 9 x 6 in., paper. 50 fr.

A French translation of Professor Ewing's "Thermodynamics for Engineers." The original has been followed very exactly

by the translator, but metric measures have been substituted for the English units in the various numerical tables.

THERMODYNAMIQUE.

By Aimé Witz. 4th edition. Paris, Gauthier-Villars et Cie. [1924]. 333 pp., 8 x 5 in., paper. 20 fr.

A brief statement of those general principles of thermodynamics which an engineer needs to know, presented in rational order and arranged for convenient reference. The book will prove useful as an introduction to the study of heat engines in general and to the theory of steam and gas engines.

The present edition has been revised and extended.

CHARLES PROTEUS STEINMETZ: A biography by John Winthrop Hammond. New York Century Co. illus. 5 by 8 in. cloth. $4.00

An authorized biography of the great engineer. See December issue of the A. I. E. E. JOURNAL, page 1217

Past Section and Branch Meetings

SECTION MEETINGS

Baltimore

Automatic Sub-Stations, by Adrian Hughes, United R. R. & Elect. Co., and C. A. Butcher, Westinghouse Elec. & Mfg. Co. Refreshments were served. October 17. Attendance 87.

Inspection trip to the new Gay Street Sub-Station of the United Railway Co. Luncheon was served. October 18. Attendance 57.

Force Feed and Motor Cylinder Oils, by J. G. O'Neill,

Rocket Fuel Separator. by W. J. Barnes,

Weir Single-Stage Centrifugal Boiler-Feed Pump, by J. B. Lincoln and

Endurance Properties of Metals, by Dr. D. J. McAdam, Jr. All-day meeting, held jointly with the A. S. M. E. at the U. S. Naval Academy, Annapolis. In the afternoon the visitors attended the Navy-Penn State Football Game. November 1. Attendance 35.

Development of Distribution System, by R. B. Mateer. Refreshments were served. November 21. Attendance 47.

Electricity in the Home, by Mrs. Elizabeth J. McDonald, Editor of Modern Priscilla, and M. O. Ryley, General Electric Co. Motion pictures and slides were shown. Supper was served. December 12. Attendance 150.

Boston

Carrier-Wave Telephony, by H. A. Affel, American Telephone & Telegraph Co., and E. F. Carter, General Electric Co. Mr. Affel discussed and illustrated the use of carrier waves in multiplex telephony, explaining in detail the method of modulation of the fundamental and the production of bands. Mr. Carter discussed the application of the same principle to telephony over high-tension transmission lines and pointed out the much broader range of frequencies permissible in this work as compared with ordinary telephony. November 11. Attendance 150

The European Outlook, by M. J. Mehren. November 19. Attendance 350.

Bees, by Prof. J. H. Morecroft. This was an illustrated talk on the life and habits of bees as observed by the speaker. December 9. Attendance 175.

Cleveland

High-Quality Transmission and Reproduction of Speech and Music, by W. H. Martin American Telephone & Telegraph Co. The talk was illustrated with slides December 18. Attendance 119.

Connecticut

Engineering Cooperation and Prosperity, by James T. Hartness, President of American Engineering Council. December 11. Attendance 100.

Denver

Radio Broadcasting, by M. P. Rice, General Electric Co. and

Technical Aspects of Broadcasting, by Harry Sadenwater, General Electric Co. After the meeting all attending made an inspection trip to the Rocky Mountain Broadcasting Station of the General Electric Co. December 20. Attendance 80.

Detroit-Ann Arbor

The Klydonograph, by J. F. Peters, Westinghouse Elec. & Mfg. Co. By means of slides, it was shown how these instruments are employed to accurately measure and record voltage surges, and indicate magnitude, polarity, steepness of application, etc. December 16. Attendance 35

Erie

Super-Power, by J. P. Morrisey, Penn Public Service Corp. December 16. Attendance 130.

Fort Wayne

Problems and Tendencies in Engineering Education, by Prof. A. A. Potter, Purdue University. Movies were shown and refreshments were served. December 18 Attendance 50.

Indianapolis-Lafayette

Popular Astronomy—A Story of the Heavens, by Harvey Mitchell Anthony. December 12. Attendance 92.

Ithaca

The Electrical Industry in England, by P. M. Lincoln, Cornell University. November 21. Attendance 35.

Controlling Electric Motors, by F. R. Fishback, Electric Controller & Mfg. Co. December 11. Attendance 75.

Los Angeles

Business Forecasting, by Prof. George J. Everle, University of Southern California. The speaker demonstrated by means of curves methods of forecasting business conditions by means of bank clearings, building permits and other factors, and

Electric-Furnace Production of Insulation Materials, by T. S. Curtis, Vitrafax Co. December 9. Attendance 121.

Madison

Paper-Insulated, Lead-Covered Cable for Power Transmission and Distribution, by D. W. Roper. Commonwealth Edison Co. January 7. Attendance 70.

Philadelphia

Electric Power Generation in Plants Requiring Low-Pressure Process Steam, by K. O. Miller, Westinghouse Elec. & Mfg. Co., and

Medium Capacity Extraction and Non-Condensing Turbines, by W. C. Newman, General Electric Co. November 10. Attendance 160.

The Physical Properties of Speech, Music and Noise, and Their Relation to Transmission Problems, by Dr. Harvey Fletcher, Research Laboratories of the Bell System. December 8. Attendance 485.

Pittsburgh

High-Voltage Underground Cables, by D. M. Simons, Standard Underground Cable Co. The speaker described the methods used in the manufacture of high-voltage cables and explained their characteristics as determined both from theory and experiment. December 9. Attendance 165.

Pittsfield

With MacMillan in the Artic, by Ralph P. Robinson. In addition to scientific observations, the speaker discussed the Eskimos and their manner of living, and

The Super-Power System of the Electric Companies Affiliated with the Consolidated Gas Company of New York, by Philip Torchio, New York Edison Co. January 8. Attendance 225.

Portland

Continuous Inductive Train-Control System Installed by Union Pacific, by R. C. Charlton, Oregon-Washington Railroad & Navigation Co. December 10. Attendance 70.

Providence

Some Operating Characteristics of Interconnected Lines, by Mr. Moore, New England Power Co. By means of a large map the extent of the interconnected high-tension transmission lines on this system was shown. December 9. Attendance 50.

St. Louis

The Properties of Speech, Music and Noise, and Their Relation to Electrical Communication, by Dr. Harvey Fletcher. November 12. Attendance 300.

The Institute, Its Members, and the Engineering Profession, by Farley Osgood, President, A. I. E. E. December 10. Attendance 122.

Schenectady

Lightning Arresters, What They Do and How They Do It, by Carl B. McEachron, General Electric Co. The lecture covered the theory of arrester operation, discussion of various types and methods of test, etc. November 21. Attendance 410.

Alternating-Current, Commutating Motors, by J. I. Hull, General Electric Co. The speaker compared the characteristics of the commutating a-c. motor with the direct-current variable-speed motor and the slip-ring induction motor and pointed out the various fields of application where alternating-current commutating motor could be applied. December 5. Attendance 360.

Seattle

The World Power Conference in London, by Dr. C. E. Magnussen, University of Washington. The speaker also told of the trip through Norway and Sweden on which he visited all of the power developments of importance. November 19. Attendance 75.

Spokane

Electric Drive and the Application of Electricity to Paper-Making Machinery, by Ed. Saunders. November 7. Attendance 22.

Springfield

Low-Head Hydroelectric Development, by G. R. Strandberg, Stone & Webster Co. The lecture was illustrated. December 15. Attendance 57.

Toledo

Modern Street Lighting, by Chas. M. Stahl, Westinghouse Company. The speaker discussed the various essentials necessary for good street lighting and also showed a lantern-type fixture with prismatic refracters for changing the distribution intensities in the various directions. December 17. Attendance 26.

Toronto

Trend in Design of Outdoor Stations and Equipment, by H. H. Rudd, Railway and Industrial Engineering Co. Lantern slides showed a number of typical stations recently installed. December 12. Attendance 62.

The Fynn-Weichsel Motor, by H. Weichsel, Wagner Electric Corp. The speaker described the theory and construction of the motor and showed slides of motors in service. December 19. Attendance 107.

Urbana

The Vacuum as an Aid in Research, by Chas. T. Knipp, University of Illinois. December 17. Attendance 83.

Utah

The Distribution of Electrical Energy, by Paul P. Ashworth, Utah Power & Light Co. After the meeting the members inspected an underground substation installed on the Main Street of Salt Lake City by the Utah Power and Light Co. December 3. Attendance 54.

Supervisory Control, by P. B. Garrett, Westinghouse Elec. & Mfg. Co. The speaker's lecture and demonstration showed that supervisory control provides a reliable means for communication with unattended station. December 18. Attendance 40.

Washington, D. C.

Muscle Shoals Power Development, by Major General Harry Taylor. The lecture was illustrated with slides. Refreshments were served. December 9. Attendance 150.

BRANCH MEETINGS

University of Arizona

Papers were given by the following students: James Wilson, Paul Sawyer, S. A. Sinclair, Edward Sinclair, and S. Vopatek. December 4. Attendance 21.

Brooklyn Polytechnic Institute

220-*kv. Transmission*, by J. Van Rensellaer Wall, Southern California Edison Co. The talk was illustrated with slides. January 8. Attendance 24.

Bucknell University

Glass Making, by J. C. Hostetter, Corning Glass Works. December 15. Attendance 70.

California Institute of Technology

Inspection trip to Pasadena power plant. December 3. Attendance 20.

University of California

Business Meeting. The following officers were elected: Chairman, R. A. Hurley; Vice-Chairman, A. H. Brolly; Secretary, J. M. Edwards; Treasurer, E. V. Noe. December 4. Attendance 40.

Carnegie Institute of Technology

Electric Control, by H. T. James, Westinghouse Electric & Mfg. Co. The speaker brought out many problems with which a control engineer is confronted in practise and showed the rapid progress of electric control in the last few years. January 7. Attendance 36.

Clemson Agricultural College

Automatic Control, by R. H. Tibbs,

The Balancing of Large Rotating Elements, by C. M. Asbill, and *D.-C. Machines for Merchant Marine Drive*, by S. L. Bell. December 4. Attendance 24.

Colorado Agricultural College

The Relation of Electricity to Agriculture. by Dr. E. A. White, and

Engineering, by President Long of the College. December 15. Attendance 55.

University of Denver

The Electrified Divisions of the Chicago, Minneapolis and St. Paul Railway, by Earl Reed, student, and

Some Notes on Synchronous Converters, by B. V. Schuler, student.

University of Iowa

The 65,000-kv-a. Generator at Niagara Falls, by E. T. Reihman,

The Creosoted Pine Telegraph Pole, by O. Williams, and

Sleet Formation on Trolley and Transmission Lines, by T. F. Volkmer.

Kansas University

Problems of Superpower Transmission, by R. L. Doherty, General Electric Co. November 4. Attendance 118.

Gas Lighting, by L. E. Allen, student, and

Modern Glassware and Reflector Units, by Clyde H. Freese, student. December 4. Attendance 28.

Marquette University

Distribution-Line Economy, by Arthur Pergande, Milwaukee Electric Railways & Light Co. December 11. Attendance 36.

Massachusetts Institute of Technology

Vacuum-Tube Voltmeters, by Ole M. Hovgaard, student. January 13. Attendance 12.

University of Minnesota

The Transportation Problems of Alaska, by Colonel Mears. Three films, entitled "An Electrical Giant," "The Potters Wheel," and "Beyond the Microscope," were shown. Joint meeting with A. S. C. E. December 10. Attendance 80.

University of Nebraska

Transmission-Line Construction, by Mr. Jackson, Continental Gas and Electric Co. January 9. Attendance 40.

University of Nevada

Mr. Babcock, Southern Pacific Railroad, gave an illustrated talk on his work with the electrification of their roads about the San Francisco Bay. December 18. Attendance 41.

New York University

The Unit System of Organization as Employed by the General Electric Company, by Mr. Clendenin. December 15. Attendance 87.

University of North Dakota

The Growth of Electricity in the Nineteenth Century, by V. M. Cleavland, and

What Radio Means to the Central Station, by James Peterson. Entertainment was furnished. December 15. Attendance 20.

Northeastern University

The Future of Radio, by Mr. Bodwich, Atlantic Radio Company. December 22. Attendance 16.

University of Pittsburgh

Talk by Mr. H. Etheridge, Pittsburgh and New Castle Railways Co. December 5. Attendance 60.

Relay Connection and Operation, by J. T. Hoffman. December 12. Attendance 28.

Control of Motors, by D. Lister. December 19. Attendance 29.

Purdue University

The Distribution and Sale of Power, by E. G. Ralston, Indianapolis Light & Heat Co. December 18. Attendance 21.

Rhode Island State College

Modern Electric Lighting Stations, by W. F. Lucker, student. The lecture was illustrated. December 4. Attendance 17.

The New Switch House of the Narragansette Electric Lighting Company, by Carl N. Thomas. The lecture was illustrated with slides. December 11. Attendance 18.

University of South Dakota

Talk was given by Mr. Makens on a new substation at New York. December 11. Attendance 9.

Syracuse University

The National Lamp Works, by A. H. Clark. October 1. Attendance 25.

The Development of Lighting, by Mr. Barnett. October 15. Attendance 25.

Super Power, by Mr. Greenman. October 22. Attendance 20. A film, entitled "The King of Rails," was shown. October 23.

Power Plant Installation, by Mr. Winkworth. November 5. Attendance 25.

A talk on the A. I. E. E. Convention at Pasadena was given by Professor Whitney. November 12. Attendance 25.

The Panama Canal, by Mr. Dunlap. November 19. Attendance 23.

The Variable-Speed Induction Motor, by J. R. Heisler. December 3. Attendance 23.

Different Types of Relays, by Mr. John. December 10. Attendance 23.

The Salmon River Power Plant, by Mr. Townsend. December 19. Attendance 25.

University of Tennessee

Inspection trip to Muscle Shoals, Lock 12 and Mitchell Dam. November 26. Attendance 18.

A talk on his trip to California, was given by Dr. C. A. Perkins. The speaker told of his visit to various engineering projects being developed in the West. Refreshments were served. December 11. Attendance 20.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—J. E. Contesti, 368 West 117th St., New York, N. Y.
2.—W. C. Finely, 211 John St., Oakland, Calif.
3.—P. G. Fossatti, 3426 S. Michigan Blvd., Chicago, Ill.
4.—F. Leon Grajales, 710 No. Medina St., San Antonio, Texas.
5.—A. Fred Hansen, 462 West 37th St., Los Angeles, Calif.
6.—G. Hizawa, Mitsubiki Shoji Kaisha, 5-1 Chome Urakucho, Tokyo, Japan.
7.—H. H. Hurd, 14302 Euclid Ave., E. Cleveland, Ohio.
8.—E. V. Karlsén, c/o Cons. Copper Mines Corp., Kimberly, Nev.
9.—H. J. Phillip, 1617 So. Burlington St., Los Angeles, Calif.
10.—W. B. Pradhan, L. E. E., Gamdevi Kennedy Bridge, Bombay, 7, India.
11.—Harry J. Rice, 58 Van Reypen Street, Jersey City, N. J.
12.—Wm. J. Shull, St. George Hotel, 60th & Blackstone Ave., Chicago, Ill.
13.—Thomas Whitmore, 1803 W. Pacific Ave., Spokane, Wash.
14.—O. B. Wooten, Texas A. & M. College, College Station, Texas.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, to install, test and maintain metering equipments. Conduct tests of electrical machinery incident to mining operations and make analysis and complete report of such tests. Determine capacities of equipment for various operations including cable and feeder requirements, hoists, fans, pumps, etc., and layout mine haulage propositions. Must be capable to phase in large power transformers and conduct tests on 22,000 volt equipment. Apply by letter with complete service record with all details of experience and reference to past employers. Salary $235 a month. Location, Pennsylvania. R-5093.

A. C. MOTOR DESIGNER, technically trained engineer, with experience in design of alternating current motors. Good opportunities. Apply by letter stating education, experience, age and salary expected. Location, East. R-5407.

POWER SALES ENGINEER, of more than average ability, for large power company. Excellent opportunity for advancement. State full particulars in first letter. Location, East. R-5322.

METER EXPERT, to supervise testing and care of big power customers watt-meters and demand meters. Must be very capable and know

metering from start to finish. Position permanent. Location, Middlewest. R-5427.

ELECTRICAL GRADUATE ENGINEER, with at least 3 years' test, A. D. design or laboratory experience. Must have ability to make comprehensive reports and working drawings necessary. Apply by letter with full details of experience, mentioning briefly some of the problems solved and how. Also age and starting salary expected. Location, Middlewest. R-5440.

ENGINEER, 35-40, who has had executive and sales experience who can invest $10,000 or $15,000 in an electrical business. Location, New York. R-5456.

METERMEN, must be familiar with single and polyphase meter testing and with G. E. type 7 demand meters; also familiar with central station meters and their testing and calibrating Apply by letter giving references and experience. Location, South. R-5504.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER with unlimited marine chief-engineer's license and some experience in operating department of a large public utility, desires position involving responsibility and chance for advancement with a progressive utility, where conscientious application will be appreciated. Excellent references. Available on reasonable notice. Minimum salary $2700. No shift work. B-7947.

ELECTRICAL ENGINEER, B. S. and E. E. fifteen years' experience testing, construction, manufacturing, design. Supervision of power plant and substation, installation of power equipment and apparatus Westinghouse Electric and Mfg. Company experience. Desires connection with manufacturer or public utility company. Available at once. B-9176.

ELECTRICAL CONSTRUCTION AND MAINTENANCE EXECUTIVE, technical graduate. Seventeen years' experience in construction, maintenance and operation of large power plants, substations, and industrial plants. Last eight years in executive positions. Desires connection as electrical superintendent or plant engineer. Age 37, married. Available upon short notice. B-9194.

ELECTRICAL ENGINEER, married, 39, considerable experience and successful record in development of intricate electro-mechanical problems. Has been accustomed to making theoretical analysis, preliminary commercial survey and carrying out of experiments, design, construction and patent routine. E. E. and M. E. degrees. Fifteen years' practice here and abroad. Minimum salary $5000. A-165.

ELECTRICAL MAINTENANCE ENGINEER, B. S. in E. E. 1921. Age 27, single. Two years operation and maintenance in a large power plant, and engineering connected with high-tension transmission lines. One year in charge as instructor in electrical repair shop. Can handle men. West preferred. Available on reasonable notice. B-8444.

ELECTRICAL ENGINEER, age 27, married, B. S. in E. E. 1920, desires change of position. Experience as foreman electrician in large manufacturing plant. At present employed on the installation of machine switching telephones as sub-foreman. Location preferably Philadelphia, although any location will be considered. Salary $3000 a year. B-9196.

YOUNG MAN, 27, desires position with future. Experienced in power plant operation and design. Location, Philadelphia. B-9209.

TECHNICAL GRADUATE, B. S. E. E. 1914, 36, married, perfect health. Eight years' practical experience, three years instruction engineering department of university. Wants public utilities, retail electrical store or opening in service department radio installations and repair, or class instruction in factory position. Available April 1st. Best references. Prefer Middle west. B-8099.

GRADUATE ELECTRICAL ENGINEER, 31, desires to make connections with engineering firm, consulting engineer, or investment bankers employing engineers. Seven years' design and research engineering experience in connection with power plants, substations, and distribution system of large electrical traction system. B-7846.

MAN with ten years' of practical experience in radio, telephones and automatic block signals, who will graduate June 1, 1925, in electrical engineering, wishes a position as assistant signal engineer, field work, or radio work. Married, one child. Location, central states. B-8911.

SALES MANAGER, age 32, graduate electrical engineer, offers a firm desiring New York City and Eastern representation part of his time, all office facilities and listing in building. Commission or salary arrangement. State nature of equipment. B-9214.

ELECTRICAL ENGINEER, college graduate, age 30, married. Seven years' experience in engineering of large hydro-electric and steam power plants. Desires position in valuation, inspection or commercial engineering department of large public utility. B-8644.

GRADUATE ELECTRICAL ENGINEER with eight years' experience building and installing hydraulic and electrical machinery. Desires connection with construction or operating company, preferably in the capacity of construction or field engineer. Thoroughly familiar with handling the erection, operation, and maintenance of large hydro-electric units. Available upon two weeks' notice. B-9217.

ELECTRICAL ENGINEER, technical graduate E. E., Assoc. Member Engineering Institute of Canada, having had a very broad experience and been in charge of all kinds of electrical construction, maintenance and operation of hydro-electric plants, substations, industrial plants and transmission lines. Can produce results. Prefer Western Canada or Western States. B-7402.

ELECTRICAL-DESIGNING DRAFTSMAN, technical education, age 25, single, seven years' experience on layout work in connection with hydro-electric generating stations, substations high and low tension, and overhead and underground distribution systems. Location immaterial. Excellent references, available on two weeks' notice. B-8628.

JUNIOR EXECUTIVE, 33, married, graduate Engineer E. E. 1913, having broad motor manufacturing and commercial experience of technical nature in automobile and electrical industry, will soon be available as a technical executive. Present connection line supervision and merchandising through national organization. Location secondary; minimum salary $4500. Interview solicited. B-9231.

RECENT GRADUATE, seeks position in electrical sales or inspection work. Now employed General Electric test floor. Single, age 23. Available short notice. Location immaterial. Salary vicinity $175. B-9235.

ELECTRICAL ENGINEER OR DESIGNER, technical graduate; testing, manufacturing engineering department, electrical construction and some sales experience. Twelve years designing, two years mechanical, four years industrial light and power, six years electric power station. Location desired northeast. Available in one week. B-9222.

PROFESSOR-ELECTRICAL ENGINEERING, ten years' of teaching experience covering all of the usual electrical engineering courses. Contact with the industry has been broad and covers general engineering, design and construction experience. Well acquainted with the educational needs of the engineering profession. Desires professorship in electrical engineering. Available in September. Salary at least $3500. B-7083.

ELECTRICAL ENGINEER, age 28, scholarship Imperial College of London. Two and one-half years' electrical testing and installation work, two years' distribution and power plant layout work. Employed at present, wishes change. Location immaterial. Highest references. Available on reasonable notice. B-9241

TECHNICAL GRADUATE, single, age 31, desires position as assistant superintendent or in distribution department of public utility company. Five years' experience in distribution engineering, one year testing, two years construction and assembly work in shops. Available on two weeks' notice. B-9248.

ELECTRICAL CONSTRUCTION FOREMAN, twelve years' experience, age 33, married, desires position with public utility or construction company. Experienced in substation, transformer station, steam and hydro-electric development. B-9258.

ELECTRICAL DESIGNING ENGINEER, technical graduate of university, age 26, single. Five years' experience on design of hydro-electric generating and transformer stations, one year in construction work. Now with firm of consulting engineers, but desires connection with company offering opportunity for advancement. B-9255.

SALES EXECUTIVE, broad electrical, mechanical experience. Excellent record, references. Well acquainted with railroad marine situation, St. Louis, Southwest and Texas points. Will consider high grade account, preferably salary, commission. Available in thirty days. B-9265.

ELECTRICAL ENGINEER, college graduate, age 30, Westinghouse students graduate course, desires position. One year underground transmission experience, two years' construction and design experience in power plants and substations. Best of references. Location preferred, New York City. B-3993.

ELECTRICAL ENGINEER, age 23, single, wishes an opportunity in an organization looking for a dependable, willing worker. A recent graduare in electrical engineering who desires to work into an executive position. Available at short notice. Location in New England preferred. B-7923.

ENGINEER, 42, experience heavy metal working machinery, general plant equipment and production work. Eight years' executive positions. Middle-west or East. B-7581.

ELECTRICAL ENGINEER, married, employed by large manufacturing company; four years' experience in design and manufacture of protective relays, their application in every field, experience in system studies, short circuit calculations. Desires position with consulting engineers or progressive power company, necessitating research or inventive ability along with practical experience and offering opportunities for advancement. B-9286.

INDUSTRIAL CONTROL SPECIALIST in the design and application of automatic control as applied to modern industry. Five years' with large manufacturing concern, two years' with public utility. Desires position with engineering or industrial concern, in engineering capacity. Technical graduate, age 28, married. B-9288.

ENGINEER experienced in the design and installation of the smaller types of power plants, including power boards, fuse panels, power machines, storage batteries, conduit plans, circuits and apparatus. Also a number of years in sales work, estimating and public utility appraisals. B-9287.

GRADUATE ELECTRICAL ENGINEER, 28, married, B. S. 1921, post graduate studies E. E., good mathematician, three years' experience design and wiring diagrams of switchboards, automatic switching equipment, familiar with all relay and protection problems. Desires permanent position with engineering firm or public utility; Philadelphia or New York City. Available two weeks' notice. B-9297.

ELECTRICAL ENGINEER, graduate 1923 electrical, hydraulic engineering, 24 single, Canadian, desires position reputable firm interested in management, engineering problems public utilities. Prefer Canada, would consider South America. Broad general experience with maintenance and operation gold mine equipment. One year G. E. Test. Present engaged transmission investigations. Available reasonable notice. B-9293.

MEMBERSHIP—Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 21, 1925

*ABRAHAM, LEONARD GLADSTONE, Electrical Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

ALLIMAN, CLARENCE LESTER, Relay Tester, East Penn Electric Co., Pottsville, Pa.

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BASTA, CARLO, Dynamo Operator, New York Edison Co., 30 E. 15th St., New York, N. Y.

BEERS, HENRY WORRELL, Merchant, H. W. Beers Electric Co., S. A., Apartado 1932, Mexico D. F., Mex.

BELT, ALVIN MAYHUGH, Operator, Potomac Electric Power Co., 450 Washington St., N. W., Washington, D. C.

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BLOSE, HOWARD S., Engineer, System Operating Dept., Pennsylvania Power & Light Co., Hazleton, Pa.

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BORST, JOSEPH ALBERT, Electrical Draftsman, Interborough Rapid Transit Co., 600 W. 59th St., New York; res., Brooklyn, N. Y.

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WOODHEAD, EDWIN ARTHUR, General Foreman, Power Plants, Idaho Power Co., Boise, Idaho.
WUNDHEILER, BORIS MICHEL, Asst. Engineer, General Electric Co., River Works, Lynn, Mass.
WYKS, JOSEPH WILLIAM, Dist. Superintendent, Public Service Electric & Gas Co., 225 N. Warren St., Trenton, N. J.
WYLIE, CAL M., Electrical Construction, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.
YAGODKIN, VLADIMIR K., Electrical Engineering Dept., Consolidated Gas Co., Monument St., Baltimore, Md.

Total 192

*Formally Enrolled Students

ASSOCIATES REELECTED JANUARY 21, 1925

IZ'UROFF, BASIL ALEXANDROVICH, Supt., Technical Dept., City of Tramway, St. of Arch. Rossi, 1/3, Leningrad, Russia.
MORRISON, LEWIS A., Design & Production Engineer, Globe Radio Equipment Co., 217 W. 125th St., New York, N. Y.
ROBERTS, SHELDON, Plant Construction & Maintenance Work, Columbus Railway, Power & Light Co., 137 W. Goodale St., Columbus, Ohio.
SPARKS, VIRGIL P., Electrical Engineer, Peerless Electric Co., Warren, Ohio.

ASSOCIATES REINSTATED JANUARY 21, 1925

DAVIS, CARLOS, Automotive Electrician, F. F. Newberry Co., 63 Warren St., Glens Falls, N. Y.
LEE, ALEXANDER WILLIAM HOWARD, Operator, Manitoba Power Co., Great Falls, Manitoba, Can.

MEMBERS ELECTED JANUARY 21, 1925

BRENT, HERBERT CYRIL, Telegraph Engineer, New Zealand Government Post & Telegraph Dept., Laboratory, Wellington, New Zealand.
EDWARDS, EDMUND PERKINS, Manager, Radio Dept., General Electric Co., Schenectady, N. Y.
GAFFENEY, CHARLES H., Superintendent of Telegraph, Central Railroad of New Jersey, C. R. R. Terminal, Jersey City, N. J.
HANSA, FREDERICK, Chief Engineer, Guaranty Trust Co., 140 Broadway; Consulting Engineer, Abell, Smalley & Myer, 220 W. 42nd St., New York; res., Great Kills, N. Y.
McWETHY, HAROLD ELBERT, Electric Railway Engineer, Railroad & Warehouse Commission, St. Paul, Minn.
PHILLIPS, HENRY BAYARD, Assoc. Professor of Mathematics, Massachusetts Institute of Technology, Cambridge, Mass.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held January 12, 1925, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

SCOTT, CHARLES F., Professor of Electrical Engineering, Yale University, New Haven, Conn.

To Grade of Member

AMSTUZ, J. O., Electrical Engineer, El. Railroad Soleure-Berne, Soleure, Switzerland
BONNETT, LELAND B., Inside Plant Engineer, Electrical Engineering Dept., Brooklyn Edison Co., Brooklyn, N. Y.
BUSHER, JOSEPH E., Superintendent, Station Construction, Kansas City Power & Light Co., Kansas City, Mo.
DORAN, JOHN E., Electrical Engineer, Electric Distribution Dept., Union Gas & Electric Co., Cincinnati, O.
OSWALD, ARTHUR A., Engineer, Research Dept., Western Electric Co., New York, N. Y.
PERRY, O. M., Manager, Windsor Hydro-Electric Systems, Windsor, Ontario
PERRY, WILLIAM W., Electrical Engineer, Binghamton Light, Heat & Power Co., Binghamton, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1925.

Adam, L. G., American Tel. & Tel. Co., Chicago, Ill.
Adams, G. G., New York Edison Co., New York, N. Y.
Alldridge, L., American Radio & Electric Co., Union Hill, N. J.
Allen, H. B., Westinghouse Elec. International Co., New York, N. Y.
Allen, T. T., Jos. T. Fewkes & Co., Philadelphia, Pa.
Allgeier, O. R., Union Electric Light & Power Co., Webster Groves, Mo.
Amann, R. E., Buffalo Forge Co., Buffalo, N. Y.
Andrew, C. J., Jr., Kansas City Power & Light Co., Kansas City, Mo.
Anderson, L. N., All America Cables, Inc., Guantanamo Bay, Cuba.
Apostal, S. D., Commonwealth Edison Co., Chicago, Ill.
Archer, W. W., Jr., Virginia Railway & Power Co., Richmond, Va.
Arntzen, B., N. J. State Bridge Tunnel Commission, New York, N. Y.
Atkinson, G. E., Toledo Edison Co., Toledo, Ohio
Barclay, A. E., Dwight P. Robinson & Co., Inc., New York, N. Y.
Beard, R. F., Phila. Mgr., Industrial Engr., *Journal of Electricity*, Philadelphia, Pa.
Beardsley, F. D., General Electric Co., Schenectady, N. Y.
Becker, N. R. A., Michigan Bell Tel. Co., Jacksonville, Fla.
Benjamin, R. N., Bureau of Power & Light, Los Angeles, Calif.
Bennett, R. H., Jr., Tennessee Electric Power Co., Chattanooga, Tenn.
Bergstrom, T., 1414 W. 62nd St., Seattle, Wash.
Best, C. A., The Pacific Tel. & Tel. Co., Fresno, Calif.
Biegel, E. J., Duquesne Light Co., Pittsburgh, Pa.
Birge, E. B., Brooklyn Edison Co., Brooklyn, N. Y.
Bjorndal, M., New York Edison Co., New York, N. Y.
Blanchard, R. I., Toledo Edison Co., Maumee, Ohio
Blomquist, E. P., Densmore, LeClair & Robbins, Boston, Mass.
Boehm, F. J., (Member), Union Electric Light & Power Co., St. Louis, Mo.
Boll, L. P., Union Electric Light & Power Co., Webster Groves, Mo.
Bousman, H. W., Allis-Chalmers Mf. Co., West Allis, Wis.
Boyden, W. G., Liberty Electric Corp., Stanford, Conn.
Breunig, R. H., Atlantic City Electric Co., Philadelphia, Pa.
Briddick, J. W., Barker, Grost & Chapman Co., Toledo, Ohio
Brody, E., Public Service Production Co., Newark, N. J.
Brown, H. C., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Brown, L. H., Crystal Lake Laboratory, Cassel, via Redding, Calif.
Burns, D., Detroit Edison Co., Detroit, Mich.
Cadwell, F. L., New York Telephone Co., New York, N. Y.
Caprin, V. I., Electr. Research Lab. Co., "ERLA" Radio Mfg., Chicago, Ill.
Carnagy, L. W., Locke Insulator Corp., Baltimore, Md.; for mail, Atlanta, Ga.
Carrick, J. E., Brooklyn Edison Co., Brooklyn, N. Y.
Carter, E. F., General Electric Co., Schenectady, N. Y.
Castellino, L. V., Union College, Schenectady, N. Y.
Chauls, R., American Machine & Foundry Co., Brooklyn, N. Y.
Chen, S. T., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Clark, H. S., Hydro-Elec. Commission of Ontario, Queenston, Ont., Can.
Clark, H. W., Western States Gas & Electric Co., Stockton, Calif.
Coates, J. O., General Electric Co., Schenectady, N. Y.
Colledge, A., Murrie & Co., New York, N. Y.,

Congleton, R. T., B. A. Wesche Electric Co., Cincinnati, Ohio.
Cook, L. E., Texas Power & Light Co., Dallas, Texas
Corrao, G., Western Electric Co., Inc., St. Louis, Mo.
Coulter, S. L., General Electric Co., Schenectady, N. Y.
Crane, C. C., Commonwealth Power Corp., Jackson, Mich.
Creamer, C. D., Michigan State Auto School, Detroit, Mich.
Crosby, P. W., Joseph E. Frechie & Co., Philadelphia, Pa.
Cross, C., Light Dept., City of Seattle, Seattle, Wash.
Cruickshank, J. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Dafoe, A. A., General Electric Co., Schenectady, N. Y.
Dahl, T. C., (Member) Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Davis, H., Jones & Laughlin Steel Corp., Woodlawn, Pa.
DaVolio, J. M., Electrical Engineer, 171 Cherry St., New York, N. Y.
Degentesh, H. E., 889 Fifth Ave., Milwaukee Wis.
de Laneux, H. H., Radio Corp. of America, Bolinas, Calif.
Dempsey, H. M., New York Edison Co., New York, N. Y.
De Renzis, J. A., Western Electric Co., Inc., Washington, D. C.
Deveau, J., North Shore Power Co., Three Rivers, Que., Can.
Diehl, E. A. P., Bell Telephone Co. of Penna., Philadelphia, Pa.
Dickinson, O., N. Y. State Dept. of Architecture, Albany, N. Y.
Dillon, E. V., General Electric Co., Pittsfield, Mass.
Doane, R. E., (Member), Standard Underground Cable Co., Pittsburgh, Pa.
(Applicant for re-election)
Dodson, J. R., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Doughty, H. C., Elec. & Trolly Utility; Ohio Service Co., Cambridge, Ohio
Douglas, F. C., Commercial Elec. Supply Co., St. Louis, Mo.
Duncan, H. D., Commonwealth Power Corp., Jackson, Mich.
Duncan, W. C., Brooklyn Edison Co., Brooklyn, N. Y.
Dunn, H. E., General Electric Co., Pittsfield, Mass.
Eadie, J. B., Saskatchewan Gov't. Telephones, Saskatchewan, Can.
Eckhardt, E. F., Illinois Bell Telephone Co., Chicago, Ill.
Eddy, R. W., Wisconsin Telephone Co., Milwaukee, Wis.
Eggens, H. J., Brooklyn Edison Co., Brooklyn, N. Y.
Eisenhower, E. D., West Penn Power Co., Charleroi, Pa.
Eisenmann, A. S., Westinghouse Radio Station WBZ, Springfield, Mass.
Ellerman, A., Moloney Electric Co., St. Louis, Mo.
Enright, J. J., Brooklyn Edison Co., Brooklyn, N. Y.
Ettlinger, E., (Member), Union Electric Light & Power Co., St. Louis, Mo.
Evans, G. G., (Member), Ohio Bell Tel. Co., Cleveland, Ohio
Evjen, I. W., College of Engineering, Milwaukee, Wis.
Faigle, C. A., New York Edison Co., Bronx, New York, N. Y.
Farquarson, S., British Columbia Elec. Ry. Co., Ltd., Vancouver, B. C.
Faunt LeRoy, H. W., (Member), Mancha Battery Locomotive Co., Baltimore, Md.
Feldman, M. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Feldsteen, J. J., Western Union Telegraph Co., Cleveland, Ohio
Ferguson, F. F., DX Radio-Lectric Co., Buffalo, N. Y.
Ferguson, W., Robertson Electric Construction Co., Buffalo, N. Y.
Ficklin, O. W., Southwestern Bell Tel. Co., St. Louis, Mo.
Finley, A. M., Union Electric Light & Power Co., St. Louis, Mo.
Flagle, F. W., University of Utah, Salt Lake City, Utah
Forbes, H. C., Zenith Radio Corp., Chicago, Ill.
Forbes-Roberts, H., Arcola Light & Power Co., Arcola, Sask., Can.
Foster, J., Safety Insulated Wire & Cable Co., Bayonne, N. J.
Fox, C. G., Brooklyn Edison Co., Brooklyn, N. Y.
Frank, A. S., Penn. State Highway Dept., Pittsburgh, Pa.
Frank, H. R., New York Edison Co., New York, N. Y.
Frenzer, P. F., Union Pacific Railroad Co., Omaha, Nebr.
Friedman, E. A., Oliver Iron Mining Co., Hibbing, Minn.
Fuqua, H. E., General Electric Co., Los Angeles, Calif.
Gahan, J. J., Officer, U. S. A., Camp Alfred Vail, N. J.
Gardner, M. V., Rochester Gas & Electric Corp., Rochester, N. Y.
Gary, A. C., American Beet Sugar Co., New York, N. Y.
Gerbersman, H. J., Southwestern Bell Tel. Co., St. Louis, Mo.
Gheen, R. F., Ohio Brass C., Los Angeles, Calif.
Gibford, C. W., Schwarze Electric Co., Adrian, Mich.
Gilleland, E. C., Puget Sound Power & Light Co., Seattle, Wash.
Glasow, O. A., Northern States Power Co., Minneapolis, Minn.
Glass, J. G., Idaho Power Co., Murphy, Idaho
Goldberg, B., Bengo Electric Corp., Brooklyn, N. Y.
Golding, L. M., Postal Telegraph Co., Chicago, Ill.
Gordon, L. B., Kelly Springfield Tire Co., Cumberland, Md.
Gotoda, K., 81 Marion Street, Brookline, Mass.
Gottron, G., Bell Telephone Laboratories, Inc., New York, N. Y.
Graham, C. W., Hatfield Electric Co., Cleveland, Ohio
Gray, A. L. B., Brazilian Telephone Co., Toronto, Ont.
Green, W. H., Union Gas & Electric Co., Cincinnati, Ohio
Greenleaf, M., Twin City Theatres Co., Centralia, Wash.
Greff, L. M., American Jobbers Supply Co., New York, N. Y.
Grimstad, R. C., Sargent & Lundy, Chicago, Ill.
Groh, G. H., West Penn Power Co., Pittsburgh, Pa.
Gudgeon, S. E., Shawinigan Water & Power Co., Shawinigan Falls, Que., Can.
Guild, F. E., Wisconsin Power & Light Co., Madison, Wis.
Gustafson, W. T., Northern Pacific Public Service Co., Bremerton, Wash.
Haddad, L. B., Public Service Electric & Gas Co., Irvington, N. J.
Hafel, C. P., University of Notre Dame, Notre Dame, Indiana.
Hagemeyer, W., Potomac Electric Power Co., Washington, D. C.
Haigh, J. H., Board of Water & Elec. Lt. Commission, Lansing, Mich.
Halaby, F. H., 68 Bay 13th St., Brooklyn, N. Y.
Hales, J. L., Carolina Power & Light Co., Raliegh, N. C.
Hammann, R. T., Brooklyn Edison Co., Brooklyn, N. Y.
Hammond, J. A., University of Minnesota, Minneapolis, Minn.
Hanford, H. H. R., Canadian Pacific Railway Co., Vancouver, B. C.
Hapgood, K. E., General Electric Co., Schenectady, N. Y.
Harris, H. D., Rensselaer Polytechnic Institute, Troy, N. Y.
Hawley, G. L., United Water, Gas & Electric Co., Hutchinson, Kans.
Hayward, S. C., The Electric Journal, Pittsburgh, Pa.
Heidelbaugh, E. C., Bell Telephone Co. of Penna., Philadelphia, Pa.
Hellern, B., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Hensley, F. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Herborn, L. E., Western Electric Co., Inc., New York, N. Y.
Heufeld, S. New York Edison Co., New York, N. Y.
Heymsfield, H. R., Heymsfield Contracting Co., New York, N. Y.
Hill, H. E., San Joaquin Light & Power Co., Bakersfield, Calif.
Hill, W. S., General Electric Co., Schenectady, N. Y.
Hogue, L. J., Commonwealth Edison Co., Chicago, Ill.
Holland, L. N., University of Michigan, Ann Arbor, Mich.
Holm, E. N., Great Western Power Co., Rio Vista, Solano Co., Calif.
Hood, J. W., Public Service Co. of No. Illinois, Evanston, Ill.
Hovey, A. G., General Electric Co., Schenectady, N. Y.
Huber, H., Northwestern Electric Co., Chicago, Ill.
Hubert, E. H., (Member), Secy., Meetings & Papers Comm., A. I. E. E., New York, N. Y.
Hungate, B. J., Union Electric Light & Power Co., St. Louis, Mo.
Hunter, E. E., The Ohio Public Service Co., Warren, Ohio
Inch, J. A., Saskatchewan Gov't. Telephones, Regina, Sask., Can.
Ingram, W. H., Texas Power & Light Co., Dallas, Texas.
Isenberg, H. D., Allen-Bradley Co., Milwaukee, Wis.
Johnstone, R. L., (Member), Elec. Engr., 611 Granit Bldg., St. Louis, Mo.
Jones, B., Dept. of Telephones, Gov't of Saskatchewan, Regina, Sask., Can.
Jones, R. H., (Member), Brooklyn Edison Co., Brooklyn, N. Y.
Kargaroff, C. M., Western Electric Co., Chicago, Ill.
Kater, J. A., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Kearney, J. R., (Member), W. N. Matthews & Bros. Corp., St. Louis, Mo.
Keirns, J. T., City of Los Angeles Bureau of Pr. & Lt., Los Angeles, Calif.
Kelly, J. M., Carnegie Inst. of Technology, Pittsburgh, Pa.
Kelly, R.B., General Electric Co., Pittsfield, Mass.
Kerns, A. D., Western Electric Co., Inc., Chicago, Ill.
Kigar, D. F., Ohio University, Ada, Ohio
Kindl, C. H., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kingburne, F., Brooklyn Edison Co., Brooklyn, N. Y.
Kilsingbury, H. G., Union Electric Light & & Power Co., St. Louis, Mo.
Kitchen, A. P., Philadelphia Electric Co., Philadelphia, Pa.
Klak, J. J., Wisconsin Telephone Co., Milwaukee, Wis.
Knight, F. V., British Columbia Electric Railway, Vancouver, B. C.
Knight, I. T., Oklahoma Agri. & Mech. College, Stillwater, Okla.
Knodél, H. S., Otis Elevator Co., St. Louis, Mo.
Kraehenbuehl, J. O., University of Illinois, Urbana, Ill.

Kruger, F. H., Western Electric Co., Chicago, Ill.
Laird, J. A., St. Louis Board of Trade, St. Louis, Mo.
Lakin, C. E., Kansas Electric Power Co., Lawrence, Kansas.
Larkin, D., (Member), Larkin Engineering Co., St. Louis, Mo.
Leal, C., Necaxa Power House, Necaxa, Puebla, Mexico
Leet, C. R., E. L. Phillips & Co., New York, N. Y.
Lejeune, G. J., Western Electric Co. Philadelphia, Pa.
Leon, H., Charles Freshman Co., New York, N. Y.
Levy, M. N., Stephenson Laboratories, New York, N. Y.
Lewis, E. H., Union Electric Light & Power Co., Webster Groves, Mo.
Liddington, S. J., Canadian Westinghouse Co., Hamilton, Ont., Can.
Lind, J. E., New York Central Railroad, New York. N. Y.
Lindsey, E. C., Public Service Co. of No. Illinois, Chicago, Ill.
Linke, E. H., New York Telephone Co., New York, N. Y.
Linney, R. W., Southwestern Bell Telephone Co., Topeka, Kans.
Lipschitz, H., Public Service Production Co., Newark, N. J.
Little, F. M., Ohio Bell Tel. Co., Cleveland, Ohio
Littlefield, J. C., Pacific Gas & Electric Co., San Francisco, Calif.
Loeber, C., (Member), Consulting Engineer, Richmond, Va.
Loewell, C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Lucas, H. C., Jr., Philadelphia Electric Co., Philadelphia, Pa.
Lung, Shun-Yeu, Foos Gas Engine Co., Springfield, Ohio
Luque, E. D., Mexican Light & Power Co., Mexico City, Mex.
Macfarlane, G. O'R., General Electric Co., St. Louis, Mo.
Macnabb, V. C., Stevens Institute of Technology, Hoboken, N. J.
Malone, A., Western Electric Co., Inc., Chicago, Ill.
Maneschi, E., Western Electric Co., Inc., Hawthorne, Ill.
Mariscal, J. F., Los Angeles Bureau of Pr. & Lt., Los Angeles, Calif.
Marsh, C. S., Philadelphia Electric Co., Philadelphia, Pa.
Marshall, A. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Martell, N. A., Murrie & Co., Inc., New York, N. Y.
Martin, F. M., Mechanics Institute, Rochester, N. Y.
Martz, C. J., Dixie Construction Co., Huntsville, Ala.
Maseng, O., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Mathes, J. A., United Electric Light & Power Co., New York, N. Y.
McDonald, K. M., University of Alabama, University P. O., Ala.
McElwee, J. H., United Electric Light & Power Co., New York, N. Y.
McLaughlin, J. L., Jr., General Electric Co., Pittsfield, Mass.
Melton, S., West Kentucky Coal Co., Sturgis, Ky.
Meseroll, C. A., Public Service Production Co., Newark, N. J.
Miers, W. S., Pacific Gas & Electric Co., San Francisco, Calif.
Miller, C. F., General Electric Co., Pittsfield, Mass.
Miller, J. M., Rice Institute, Houston, Texas
Milligan, J. I., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Mithoug, O. J., Pittsburgh Transformer Co., Pittsburgh, Pa.
Moat, C. W., Hydro-Elec. Pr. Comm. of Ontario, Toronto, Ont.
Mohr, E. J., Wisconsin Telephone Co., Milwaukee, Wis.
Monk, N., American Tel. & Tel. Co., New York, N. Y.
Morgoglione, V., Western Electric Co., Inc., New York, N. Y.
Moser, F. L., Southern Power Co., Charlotte, N. C.
Moser, M. X., Wisconsin Telephone Co., Madison, Wis.
Mosher, F. L., Edison Elec. Illuminating Co. of Boston, Boston, Mass.
Mouromtseff, I. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Mulligan, J. R. A., Bell Telephone Co. of Penna., Philadelphia, Pa.
Murphy, H. O., Stone & Webster, Inc., Boston, Mass.
Musselman, R. D., General Electric Co., Schenectady, N. Y.
Naylor, J. B., General Electric Co., Schenectady, N. Y.
Neumann, J. J., National Sugar Refining Co., Long Island City, N. Y.
Newman, A. F., The Stamford Gas & Electric Co., Stamford, Conn.
Nicholson, C. H., Murrie & Co., New York, N. Y.
Nickle, C. A., General Electric Co., Schenectady, N. Y.
Nih, A. T., New York Edison Co., New York, N. Y.
Nile, J., Public Service Production Co., Newark, N. J.
Noel, A. W., Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Nyholm, C., Jydsk-Telephon Co., Aashus, Denmark; for mail, New York, N. Y.
Nyman, R. J., Pullman Car & Mfg. Co., Chicago, Ill.
Oakes, S. B., 1020 Boatmen's Bank Bldg., St. Louis, Mo.
Packer, L. C., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Papp, E. G., Indianapolis Light & Heat Co., Indianapolis, Ind.
Parmelee, R. H., The Counties Gas & Electric Co., Norristown, Pa.
Pattison, E. J., Government Telephones, Moosomin, Sask., Can.
Pearce, L. G., General Electric Co., Atlanta, Ga.
Penn, A., Garod Radio Corp., Newark, N. J.
Perkins, A. T., (Member), United Rwys. Co. of St. Louis, St. Louis, Mo.
Peterson, T. F., Brooklyn Edison Co., Brooklyn, N. Y.
Phelps, G. E., Milwaukee Elec. Railway & Light Co., Milwaukee, Wis.
Pohl, F. C., Detroit Edison Co., Detroit, Mich.
Pollard, G. M., Buffalo General Electric Co., Buffalo, N. Y.
Potts, J. A., The Milwaukee Elec. Ry. & Light Co., Milwaukee, Wis.
Preston, H. R., General Electric Co., Schenectady, N. Y.
Preston, J. H., N. Y. State Bridge & Tunnel Commission, New York, N. Y.
Pullen, C. E., (Member), Pullen-Zoll Electric Co., Miami, Fla.
Randall, P. M., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Rankine, J. C., Great Northern Railway, St. Paul, Minn.
Rauchfleisch, B. J., Commonwealth Edison Co., Chicago, Ill.
Reeve, H. E., Des Moines Electric Co., Des Moines, Iowa
Rice, P. X., Miller Train Control Corp., Danville, Ill.
Rich, A., Union Electric Light & Power Co., St. Louis, Mo.
Rigant, E., Jr., Brooklyn Edison Co., Brooklyn, N. Y.
Ringold, H. R., H. R. Auto Electric Service Co., Grand Rapids, Mich.
Rissberger, J. M., Crown Willamette Paper Co., West Linn, Oregon
Robinson, L. W., Commonwealth Power Corp., Jackson, Mich.
Rommel, E., Union Miniere Du Haut Katanga (Brussels), New York, N. Y.
Ross, E. A., Jr., General Electric Co., Schenectady, N. Y.
Ross, R. R., Nebraska Power Co., Omaha, Nebr.
Roth, R., 30 Church St., New York, N. Y.
Russell, C. C., Jr., Edison Lamp Works, of G. E. Co., Harrison, N. J.
Sampson, C. L. University of Minnesota, Minneapolis, Minn.
Sanders, E. C., *Gen. Elec. Review* of G. E. Co., Schenectady, N. Y.
Sandman, D., Frank Ridlon Co., Boston, Mass.
Saunders, J. B., H. W. Newman Electric Co., Kingston, Ont., Can.
Scheering, W. S., Stone & Webster, Inc., Boston, Mass.
Schneider, E. T., The New York Edison Co., New York, N. Y.
Schregardus, D., Ohio Bell Telephone Co., Cleveland, Ohio.
Schultz, S. E., Consumers Power Co., Jackson, Mich.
Schweizer, F. W., Brooklyn Edison Co., Brooklyn, N. Y.
Seamon, K. G., Public Service Co. of Colorado, Boulder, Colo.
Searponi, R. U., Brooklyn Edison Co., Brooklyn, N. Y.
Seely, H. B., Brooklyn Edison Co., Brooklyn, N. Y.
Seigman, P. C., Philadelphia Suburban Gas & Elec. Co., Wyncote, Pa.
Senior, A. H., Feeder Dam, Hydro-Electric Station, Glens Falls, N. Y.
Severe, L. J., Pacific Gas & Electric Co., San Francisco, Calif.
Shaughness, C. E., Jr., Fordham Law School, New York, N. Y.
Sidwell, L. W., University of Utah, Salt Lake City, Utah
Skillman, W. T., New York Telephone Co., New York, N. Y.
Skinner, V. O., Illinois Bell Telephone Co., Chicago, Ill.
Skoglund, C., General Electric Co., Lynn, Mass.
Sleeman, H. P., The R. Thomas & Sons Co., East Liverpool, Ohio
Smith, C. C., Commonwealth Edison Co., Chicago, Ill.
Snodgrass, F. C., American Tel. & Tel. Co., Cleveland, Ohio
Stansfield, D. W., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
St. Denis, C. W., Scanlon Supply Co., St. Louis, Mo.
Stearns, M. B., Western Electric Co., Philadelphia, Pa.
Stebbins, C., Virginia Railway & Power Co., Richmond, Va.
Stevens, R. F., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Stewart, D. C., Niagara, Lockport & Ontario Co., Buffalo, N. Y.
Stockton, F. H., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Stoddard, R. R., General Electric Co., Lynn, Mass.
Strahan, H. C., Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.
Suhr, H. F., Wisconsin Telephone Co., Milwaukee, Wis.
Summers, H. A., Bell Telephone Laboratories, Inc., New York, N. Y.
Swiedom, E. A., General Electric Co., Schenectady, N. Y.
Tatnall, J. S., Bell Telephone Co. of Penna., Philadelphia, Pa.
Thompson, R. P., Pacific Tel. & Tel. Co., Los Angeles, Calif.
Thomson, C. Otis Elevator Co. of Missouri, St. Louis, Mo.
Todd, G. C., Nickel Plate Railroad, Cleveland, Ohio

Trescott, J. B., (Member), Commercial Elec. Supply Co., St. Louis, Mo.
Trube, C. E., Thermiodyne Radio Corp., Maplewood, N. J.
Tubbs, W. E., West Penn Power Co., Pittsburgh, Pa.
Tucker, W. H., The Hoover Co., North Canton, Ohio.
Tuites, C. E., Consumers Power Co., Saginaw, Mich.
Ungar, H., General Electric Co., Schenectady, N. Y.
Van Keuren, R. G., Norton Co., Worcester, Mass.
Vieth, W. F., Western Electric Co., Inc., New York, N. Y.
Vincent, H. L., General Electric Co., Portland, Ore.
Vitullo, Ezio, 201 E. 14th St., New York, N. Y.
Voepel, E. W. C., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Voorhees, J. S., Brooklyn Edison Co., Brooklyn, N. Y.
Ward, A. C., Western Electric Co., Inc., Chicago, Ill.
Weis, J. E., Union Electric Light & Power Co., St. Louis, Mo.
Werres, C. O., General Electric Co., Schenectady, N. Y.
Westermark, A., Bureau of Power & Light, Los Angeles, Calif.
Whitman, V. E., Bureau of Standards, Washington, D. C.
Wickus, R. W., Wisconsin Power & Light Co., Madison, Wis.
Wilder, R., New York Electrical School, New York, N. Y.
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Williams, T. W., The Bell Telephone Co. of Penna., Philadelphia, Pa.
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Zeglio, L. P., Brooklyn Edison Co., Brooklyn, N. Y.
Total 285

Foreign

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Gati, B., Post & Telegraph Technical Director, Budapest 1X, Austria, Hungary. (Applicant for re-election)
Johns, L. S., Carrick-Weederspoon, Ltd., Christchurch, N. Z.
Randall, W., Associated Power Co. Ltd., Charanpur P. O., Dist., Burdwan, India
Volkman, E., Ferguson Pailin Ltd., Higher Openshaw, Manchester, Eng.
Total 6

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Allen, W. Morgan, State College of Washington
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Oregon Agri. Coll., Corvallis, Ore.	F. C. Mueller	W. D. Bridges
Pennsylvania State College, State College, Pa.	C. MacGuffie	J. H. Schmidt
Pennsylvania, Univ. of, Philadelphia	H. W. Steinhoff	J. W. Emling
Pittsburgh, Univ. of, Pittsburgh, Pa.	E. A. Casey	J. E. Lange
Purdue Univ., Lafayette, Ind.	S. B. Mills	M. G. Seim
Rensselaer Poly. Inst., Troy, N. Y.	F. M. Sebast	C. E. Daniels
Rhode Island State Coll. Kingston, R. I.	C. S. North	D. Brown
Rose Poly. Inst., Terre Haute, Ind.	P. Wilkens	R. A. Reddie
Rutgers University, New Brunswick, N. J.	W. S. Dunn	H. Crowley
South Dakota, Univ. of, Vermillion, S. D.	C. Barret	H. Babb
Southern California, Univ. of, Los Angeles, Calif.	H. A. McCarter	Chet Little
Stanford Univ., Stanford University, Calif.	M. L. Wiedmann	F. E. Crever
Swarthmore Coll., Swarthmore, Pa.	C. J. Wenzinger	J. S. Donal, Jr.
Syracuse Univ., Syracuse, N. Y.	E. J. Agnew	W. E. Phillips
Tennessee, Univ. of, Knoxville, Tenn.	S. R. Woods	F. J. Guice
Texas A. & M. Coll., College Station	A. A. Ward	L. H. Cardwell
Texas, Univ. of, Austin, Tex.	A. A. Bown	J. B. Coltharp
Utah, Univ. of, Salt Lake City, Utah	S. W. Pixton	H. H. Tracy
Virginia Military Inst., Lexington	H. F. Watson	J. P. Black
Virginia Poly. Inst., Blacksburg, Va.	E. M. Melton	M. R. Staley
Virginia, Univ. of, University, Va.	W. A. Whitaker	H. H Long
Washington, State Coll. of, Pullman	R. P. Fridlund	C. H. Backus
Washington Univ., St. Louis, Mo.	E. Zimmerman	S. E. Newhouse, Jr.
Washington, Univ. of, Seattle, Wash.	John M. Weir	J. W. Lewis
West Virginia Univ., Morgantown	W. W. Mountain	J. U. Neill
Wisconsin, Univ. of, Madison, Wis.	R. R. Benedict	H. E. Reinhold
Yale Univ., New Haven, Conn.	E. H. Eames	F. F. Tomaino
Total 79.		

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Motors.—Bulletin 141, 4 pp. Describes Wagner repulsion-induction motors, BA type. Wagner Electric Corporation, St. Louis, Mo.

Motors.—Bulletin, 4 pp. "How Century Polyphase Motors Are Built." The Century Electric Company, 1827 Pine Street, St. Louis, Mo.

Transformers.—Bulletin 2036, 4 pp., on general design; and Bulletin 2037, 4 pp., high voltage power transformers. Pittsburgh Transformer Company, Pittsburgh, Pa.

Boilers.—Bulletin 52, 36 pp. Describes Heine longitudinal drum boilers; H-type, horizontally baffled and HC-type, cross baffled. Heine Boiler Company, Inc., St. Louis, Mo.

Steam Turbine Lubrication.—Instruction Bulletin 82277, 8 pp. Devoted to a description of the lubricating system for Curtis steam turbines. General Electric Company, Schenectady, N. Y.

Fans.—Bulletin 37, 16 pp. Describes "Century" portable and ceiling, a-c. and d-c. fans. Century Electric Company, 1827 Pine Street, St. Louis, Mo.

Electrical Fittings.—Catalog 412, 60 pp. Describes a comprehensive line of electrical specialties; conduit, armored cable, boxes, fittings, connectors, etc., with prices. Bonnell Electric Mfg. Company, 192 Chambers Street, New York.

Circuit Breakers.—Bulletin 47495.1, 32 pp. Describes four improved types of General Electric circuit breakers. The new types are all for controlling and protecting circuits of large capacities. General Electric Company, Schenectady, N. Y.

Heating Element.—Bulletin, 12 pp. Describes "Globar," a non-metallic heating unit for industrial and domestic use. The material constituting the element is, in part, silicon-carbide and somewhat resembles the compound which is known commercially as carborundum. It is moulded into round bar shapes and is mechanically strong and rigid regardless of temperature applied. It is claimed that the life of "Globar" material, even when operated at temperatures up to 2400° F. is more than satisfactory and has proven durability greater than metallic elements. American Resistor Company, Milwaukee, Wis.

NOTES OF THE INDUSTRY

Roller-Smith Company 12 Park Place, New York, announces the appointment of W. H. Pugh as its representative in the northestern part of Pennsylvania with headquarters at the factory in Bethlehem, Pa. Before Mr. Pugh engaged in sales work for the Roller-Smith Company, he was superintendent of the factory.

Pure Carbon Company, Wellsville, N. Y., has appointed H. H. Miller, 7719 Lyman Street, as Pittsburgh representative; and the Simpson Power Equipment Company, 7016 Euclid Avenue, for their Cleveland territory. A local sales office has also been opened at Detroit, Michigan, General Motors Building.

Wagner Electric Corporation, St. Louis, Mo., which has recently embarked upon the manufacture of a new line of fans for domestic and general use, has organized a Fan Sales Department with L. L. Goding as manager. I. Elkas has been appointed special representative of the Fan Sales Department.

The Sangamo Electric Company, Springfield, Ill., has opened a direct sales office in Boston, located at 19 Pearl Street, in charge of Stafford J. King, who for the past twelve years has been the Sangamo sales engineer located in the New England territory. Associated with Mr. King will be Leonard G. Hunt, W. H. Carpenter and R. D. Savage. A complete stock of meters and accessories will be carried in Boston.

The Okonite Company will open an office at 310 South Michigan Avenue, Chicago, on February 1st and will take over the sale of Okonite products in the western territory. Charles E. Brown, formerly Vice-President of the Central Electric Co., has been appointed vice-president in charge of the territory west of Pittsburgh and east of the Rocky Mountains of the Okonite Company, with headquarters in Chicago. A. L. McNeill, formerly manager of the railroad department of the Central Electric Co., has been appointed manager of the railroad department. E. H. McNeill, formerly railroad sales representative of the Central Electric Co., has been appointed sales engineer. Ray N. Baker, formerly railroad sales representative of the Central Electric Company, has been appointed sales engineer. L. R. Mann, formerly sales representative of the Central Electric Company, with headquarters at St. Louis, has been appointed manager of the St. Louis office. Joseph O'Brien, formerly railroad sales representative, of the Central Electric Company, has been appointed sales representative, with headquarters in Chicago. C. E. Brown, Jr., formerly country sales manager of the Central Electric Company, has been appointed manager of the light and power department.

The Okonite-Callender Cable Company, Inc., has purchased a plant in Paterson, N. J., where it will manufacture lead-covered paper insulated cables.

General Electric Orders Show Increase.—Orders received by the General Electric Company for the three months ending December 31, totalled \$80,009,978, an increase of 7% over the same quarter in 1923, according to figures made public by Owen D. Young, Chairman of the Board of Directors. For the year 1924 orders totalled \$283,107,697, as compared with \$304,199,746 for 1923, a decrease of 7%.

Transmission Poles to be Made from Copper Bearing Steel.—It is announced by the Truscon Steel Company, Youngstown, Ohio, that in the future its steel poles will be manufactured from copper bearing steel. It is claimed that such steel will not rust and through its use the cost of galvanizing will be eliminated, and the high maintenance cost of painting much reduced.

A New Non-Metallic Armored Cable.—Patents were recently granted to the Rome Wire Company on its new non-metallic armored cable "RomeX." The manufacturers believe that when the Underwriters approve of the use of "Rome X," this wire is destined to fill an important place in the electrical wiring field. Under the broad claims of the patent as issued, the company feels it is now in a position to guarantee to the industry a high standard of quality of this product, not only as manufactured by it, but also by such other manufacturers as may be licensed to operate under the Rome patent.

Niagara Falls to be Permanently Illuminated. Searchlights of a billion and a third candle power will be used for illuminating the Falls every night with light of ever changing colors, according to an announcement by the General Electric Company. International cooperation has assured the success of the project. Both of the cities of Niagara Falls (New York and Ontario), together with the Victoria Park Commission and the Ontario Power Company, have pledged their support to the project, which represents an expenditure of \$60,000 for the installation and operation during the first year. It is planned to have the Falls illuminated four hours nightly and to have light and color drills on special occasions, possibly once a week. Present plans call for such a drill on Queen Victoria's birthday, May 24, by which date it is expected the installation will be completed. Another color drill will be held on Memorial Day, May 30. All of the searchlights are to be located on the Canadian side, at a point near the transformer house of the Ontario Power Company, by which company the necessary power is to be contributed.